DOCUMENT RESUME

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IDENTIFIERS	Military Curriculum Project

ABSTRACT

This three-volume textbook and three student workbooks for a secondary-postsecondary level course in aircraft electrical repair comprise one of a number of military-developed curriculum packages selected for adaptation to vocational instruction and curriculum development in a civilian setting. The purpose stated for the individualized, self-paced course is to provide the theory part of on-the-job training to upgrade an apprentice (semi-skilled) worker to a specialist (skilled level). The course contains basic information and some supervisory training but requires that the student have background in basic electricity and electronics. Volume 1 (seven chapters) covers flight-line safety, major aircraft systems and electrical maintenance and inspection, portable test equipment, electrical circuit functions, solid state control circuits, and application of electron tubes. Volume 2 (six chapters) discusses aircraft batteries and servicing equipment, power system test equipment, DC generator systems, transformer-rectifier power systems, AC generator systems, and motors and inverters. Volume 3 (six chapters) covers landing gear and associated systems, flight control electrical systems, warning circuits, fuel systems, power plant and related control circuits, and utility systems. Workbook contents include objectives, chapter review exercises and answers, and volume review exercises. (YLB)

MILITARY CURRICULUM MATERIALS

The military-developed curriculum materials in this course package were selected by the National Center for Research in Vocational Education Military Curriculum Project for dissemination to the six regional Curriculum Coordination Centers and other instructional materials agencies. The purpose of disseminating these courses was to make curriculum materials developed by the military more accessible to vocational educators in the civilian setting.

The course materials were acquired, evaluated by project staff and practitioners in the field, and prepared for dissemination. Materials which were specific to the military were deleted, copyrighted materials were either omitted or approval for their use was obtained. These course packages contain curriculum resource materials which can be adapted to support vocational instruction and curriculum development.

The National Center Mission Statement

The National Center for Research in Vocational Education's mission is to increase the ability of diverse agencies, institutions, and organizations to solve educational problems relating to individual career planning, preparation, and progression. The National Center fulfills its mission by:

- Generating knowledge through research
- Developing educational programs and products
- Evaluating individual program needs and outcomes
- Installing educational programs and products
- Operating information systems and services
- Conducting leadership development and training programs

FOR FURTHER INFORMATION ABOUT
Military Curriculum Materials
WRITE OR CALL

Program Information Office
The National Center for Research in Vocational Education
The Ohio State University
1960 Kenny Road, Columbus, Ohio 43210
Telephone: 614/486-3655 or Toll Free 800/848-4815 within the continental U.S., (except Ohio)

THE NATIONAL CENTER
FOR RESEARCH IN VOCATIONAL EDUCATION

Military Curriculum Materials for Vocational and Technical Education

Information and Field Services Division

The National Center for Research in Vocational Education

Military Curriculum Materials Dissemination Is . . .

an activity to increase the accessibility of military-developed curriculum materials to vocational and technical educators.

This project, funded by the U.S. Office of Education, includes the identification and acquisition of curriculum materials in print form from the Coast Guard, Air Force, Army, Marine Corps and Navy.

Access to military curriculum materials is provided through a "Joint Memorandum of Understanding" between the U.S. Office of Education and the Department of Defense.

The acquired materials are reviewed by staff and subject matter specialists, and courses deemed applicable to vocational and technical education are selected for dissemination.

The National Center for Research in Vocational Education is the U.S. Office of Education's designated representative to acquire the materials and conduct the project activities.

Project Staff:

Wesley E. Budke, Ph.D., Director
National Center Clearinghouse

Shirley A. Chase, Ph.D.
Project Director

What Materials Are Available?

One hundred twenty courses on microfiche (thirteen in paper form) and descriptions of each have been provided to the vocational Curriculum Coordination Centers and other instructional materials agencies for dissemination.

Course materials include programmed instruction, curriculum outlines, instructor guides, student workbooks and technical manuals.

The 120 courses represent the following sixteen vocational subject areas:

Agriculture	Food Service
Aviation	Health
Building & Construction Trades	Heating & Air Conditioning
Clerical Occupations	Machine Shop
Communications	Management & Supervision
Drafting	Meteorology & Navigation
Electronics	Photography
Engine Mechanics	Public Service

The number of courses and the subject areas represented will expand as additional materials with application to vocational and technical education are identified and selected for dissemination.

How Can These Materials Be Obtained?

Contact the Curriculum Coordination Center in your region for information on obtaining materials (e.g., availability and cost). They will respond to your request directly or refer you to an instructional materials agency closer to you.

CURRICULUM COORDINATION CENTERS

EAST CENTRAL
Rebecca S. Douglass
Director
100 North First Street
Springfield, IL 62777
217/782-0759

NORTHWEST
William Daniels
Director
Building 17
Airdustrial Park
Olympia, WA 98504
206/753-0879

MIDWEST
Robert Patton
Director
1515 West Sixth Ave.
Stillwater, OK 74704
405/377-2000

SOUTHEAST
James F. Shill, Ph.D.
Director
Mississippi State University
Drawer DX
Mississippi State, MS 39762
601/325-2510

NORTHEAST
Joseph F. Kelly, Ph.D.
Director
225 West State Street
Trenton, NJ 08625
609/292-6562

WESTERN
Lawrence F. H. Zane, Ph.D.
Director
1776 University Ave.
Honolulu, HI 96822
808/948-7834

AIRCRAFT ELECTRICAL REPAIRMAN

Table of Contents

AIRCRAFT ELECTRICAL REPAIRMAN

Developed by:

United States Air Force

Development and Review Dates

April 1976

Occupational Area:

Aviation

Cost: $11.25

Print Pages 557

Availability:
Military Curriculum Project, The Center for Vocational Education, 1960 Kenny Rd., Columbus, OH 43210

Suggested Background:

Basic electricity/electronics

Target Audiences:

Grades 10-adult

Organization of Materials:

Student workbooks with objectives, assignments, review exercises and answers, volume review exercises; text

Type of Instruction:

Individualized, self-paced

Type of Materials:		No. of Pages:	Average Completion Time:
Volume 1 —	*Aircraft Electrical Systems and Circuit Operations*	168	Flexible
	Workbook	61	
Volume 2 —	*Aircraft Power Systems*	130	Flexible
	Workbook	58	
Volume 3 —	*Aircraft Control and Warning Systems*	90	Flexible
	Workbook	30	

Supplementary Materials Required:

None

Expires July 1, 1978

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Course Description

This course is designed as the theory part of on the-job training to upgrade an Apprentice (semi-skilled) worker to a Specialist (skilled) level. It contains basic information and some supervisory training, but requires that the student have background in basic electricity and/or electronics *

This course contains three volumes accompanied by student workbooks and supplemental diagrams.

Volume 1 – *Aircraft Electrical Systems and Circuit Operation* contains seven chapters covering flight line safety for the electrician, major aircraft systems and electrical maintenance and inspection, portable test equipment for the electrician, electrical circuit functions, solid state control circuits, and application of electron tubes. The chapter on a maintenance organization was deleted because it referred to specific military procedures.

Volume 2 – *Aircraft Power Systems* contains six chapters discussing aircraft batteries and servicing equipment, power system test equipment, DC generator systems, transformer-rectifier power systems, AC generatory systems, and motors and inverters

Volume 3 – *Aircraft Control and Warning Systems* contains six chapters covering landing gear and associated systems, flight control electrical systems, warning circuits, fuel systems, power plant and related control circuits, and utility systems.

Each of the chapters contains objectives, readings, review exericses and answers, and volume review exercises. The course was designed for student self-study and evaluation in a shop or on-the-job learning situation.

**Aircraft Electrical Repairman* is part of a two course series. The second course, *Aircraft Electrical Repair Technician* (2-2), is designed to upgrade the Specialist-level worker to the Technician (advanced) level.

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CDC 42351

AIRCRAFT ELECTRICAL REPAIRMAN

(AFSC 42350)

Volume 1

Aircraft Electrical Systems and Circuit Operation

2-1.

Extension Course Institute

Air University

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PREPARED BY DEPARTMENT OF AIRCRAFT AND MISSILE SPECIALIST TRAINING 3345TH TECHNICAL SCHOOL (ATC) CHANUTE AFB, ILLINOIS 61866

EXTENSION COURSE INSTITUTE, GUNTER AIR FORCE BASE, ALABAMA

THIS PUBLICATION HAS BEEN REVIEWED AND APPROVED BY COMPETENT PERSONNEL OF THE PREPARING COMMAND IN ACCORDANCE WITH CURRENT DIRECTIVES ON DOCTRINE, POLICY, ESSENTIALITY, PROPRIETY, AND QUALITY.

Preface

IN THIS FIRST volume of Course 42351, we begin in Chapter 1 with a discussion of a typical maintenance organization. This is a very important chapter because it points out the overall mission of an aircraft electrical maintenance activity. You will also learn about your job, as well as that of an aircraft electrical repair technician and the aircraft electrical superintendent. Related area responsibilities and training are also presented in this chapter.

Chapter 2 is intended to provide you with a general knowledge of the hazards to safety that you will encounter in your day-to-day work, both on the flight line and in the shop.

Chapter 3 provides the 5-skill level knowledge requirements related to fluids, lubricants, color codes applicable to fluids and lubricants, aircraft-familiarization, switches, relays, and protective devices. The chapter continues with a discussion of the skills required to identify, select, and prepare aircraft wiring, connector plugs, and terminals for aircraft installation. The use of special tools required to perform wire maintenance is described. The requirements for installation and inspection of aircraft wiring, conduit "J" boxes, bus bars, bonding, and emergency repair of aircraft wiring are discussed. Finally, the requirements related to the selection and use of structural hardware and the types and uses of safety wire are discussed.

Since a great deal of your duties as an electrician require you to make accurate measurement of the values in electrical circuits, Chapter 4 discusses measuring devices. This chapter briefly reviews meter principles and explains the steps and procedures in the operation and use of multimeters, frequency meters, oscilloscopes, electron tube testers, and the Wheatstone bridge.

Chapter 5 serves as a brief review of electrical principles. It starts with a brief discussion of the nature of matter and the basic laws of magnetism. The electromagnetic field and the generation of an electromagnetic force are also discussed. Chapter 5 also shows you how to compute the various values of the sine wave. In many ways, this chapter serves to introduce material that is expanded upon later in the course.

Chapter 6 is entitled "Electrical Circuit Functions." As an aircraft electrician, you must know the basic relationships between voltage, current, and resistance or impedance. This chapter shows you how to analyze electrical circuits of all types, both AC and DC, regardless of how these circuits are connected. As a result of the knowledge you will gain in this chapter, the problem of troubleshooting should become much easier for you.

Chapter 7 provides you with the necessary background knowledge to understand the operation of solid state control circuits. The coverage in this area includes a discussion of transformers, magnetic amplifiers, transistors, and basic switching circuits. The foundation you gain from this material will help you understand the more advanced circuitry presented in Volume 2 and Volume 3.

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The final chapter in this volume reviews the basic operation of electron tubes. After this review the chapter discusses electronic power supplies and amplifier circuits. Since the aircraft electrician is required to troubleshoot, or repair, electronic equipment, it is vital that you become familiar with amplifiers and power supplies. These components are used in a great many aircraft systems as well as shop test equipment.

Figures 44–101 can be found printed and bound in the back of this volume on foldouts 1 thru 7. Whenever you are referred to one of these figures in the text, please turn to back of the volume and locate it on the foldout.

If you have questions on the accuracy or currency of the subject matter of this text, or recommendations for its improvement, send them to Tech Tng Cen (TSOC), Chanute AFB, Illinois 61868.

If you have questions on course enrollment or administration, or on any of ECI's instructional aids (Your Key to Career Development, Study Reference Guides, Chapter Review Exercises, Volume Review Exercises, and Course Examination), consult your education officer, training officer, or NCO, as appropriate. If he can't answer your questions, send them to ECI, Gunter AFB, Alabama 36114, preferably on ECI Form 17, Student Request for Assistance.

Material in this volume is technically accurate, adequate, and current as of April 1970.

Volume 1 is valued at 51 hours (17 points).

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LIST OF CHANGES

COURSE NO.	CAREER FIELDS, POLICIES, PROCEDURES AND EQUIPMENT CHANGE. ALSO ERRORS OCCASIONALLY GET INTO PRINT. THE FOLLOWING ITEMS UPDATE AND CORRECT YOUR COURSE MATERIALS. PLEASE MAKE THE INDICATED CHANGES.
42351	
EFFECTIVE DATE OF SHIPPING LIST 30 Apr 76	

1. CHANGES FOR THE TEXT: VOLUME 1

a. Page 7, para 2-16, line 17: Change the word "then" to "than."

b. Page 9, para 2-30, line 10: Change "Guide for Planning and Conducting OJT" to "On-the-Job Training."

c. Page 11, para 2-31, line 2: Change "Regulation 50-26" to "Manual 50-23." Line 3: Delete the words "Functional Responsibilities for."

d. Page 62, para 11-79, line 10: Change "turned" to "tuned."

e. Page 115, Figure 110B: Change "it" to "IT", "i1" to "I1", and "i2" to "I2."

f. Page 122, Figure 119: Change "VB8" to "VBB."

g. Page 124, Figure 122A: Reverse the polarity of the battery V_{EE}.

h. Page 152, Bibliography, line 2: Change the date "20 May 1968" to "25 February 1972." Line 3: Change the title of the manual to read "On-the-Job Training." Change the date "23 October 1967" to "1 March 1972." Line 4: Between the words "AFM 127-101" and "Accident" add "Industrial Safety." Change the date "30 December 1965" to "26 June 1970." Line 5: Delete. Line 8: Add "Change 1 May 1971" after the date. Line 9: Change the date "6 May 1968" to "30 December 1970." Line 12: Change date "15 December 1967" to "15 June 1970." Line 13: Change date "15 July 1967" to "30 July 1971." Line 15: Add "Change 15 July 1969." Line 17: Add "Change 10 January 1972." Line 18: Add "Change 15 February 1969." Line 19: Add "Change 15 October 1970." Last line: Add "Change 30 November 1967."

2. CHANGES FOR THE TEXT: VOLUME 3

a. Page 39, para 10-9, lines 5 thru 8: Delete the sentence "When these . . . to an engine."

b. Page 44, col 2, lines 11, 12 and 13: Delete the sentence "When switch Nr. 13 . . . be deenergized."

c. Page 45, para 10-35, last line: Change "23" to "24."

d. Page 83, Bibliography, line 4: Add "Change 10 July 1971." Line 6: Change "19 September 1963" to "1 March 1968." On the same line, add "Change 15 April 1971." Line 10: Add "Change 18 December 1969." Line 12: Add "Change 31 January 1969." Line 14: Add "Change 15 May 1970." Line 16: Add "Change 15 February 1966." Line 21: Add "Change 15 February 1966."

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LIST OF CHANGES

COURSE NO. 42351	CAREER FIELDS, POLICIES, PROCEDURES AND EQUIPMENT CHANGE. ALSO ERRORS OCCASIONALLY GET INTO PRINT. THE FOLLOWING ITEMS UPDATE AND CORRECT YOUR COURSE MATERIALS. PLEASE MAKE THE INDICATED CHANGES.
EFFECTIVE DATE OF SHIPPING LIST 30 Apr 76	

3. CHANGES FOR THE VOLUME WORKBOOK: VOLUME 1

a. Page 41, Answers For Chapter Review Exercises, answer 26: Change to read "AFM 50-23, On-The-Job Training."

b. Page 55, question 28: In the stem of the question, change "O-C" to "AC."

c. Page 61, question 97: In the stem of the question, change "changing" to "charging."

d. Page 64, question 119: Change the stem of the question to read "Positive feedback is useful in." Question 123: In the stem of the question, change "or" to "of."

e. The following questions are no longer scored and need not be answered: 25, 52, 100 and 119.

4. CHANGES FOR THE VOLUME WORKBOOK: VOLUME 2

a. Page 36, Chapter Review Exercises, answer 21: Change to read "State of charge is determined by discharging the battery and measuring the amount of discharge to the cut off voltage."

b. Page 36, Chapter Review Exercises, answer 22: Change to read "Nickel-cadmium batteries are charged by the constant-current method only."

c. The following questions are no longer scored and need not be answered: 8, 17, 25, 39, 82, 90, 92, 94, 103, 106 and 122.

5. CHANGE FOR THE VOLUME WORKBOOK: VOLUME 3

The following questions are no longer scored and need not be answered: 13, 36, 38 and 57.

NOTE: Change the currency date on all volumes to "April 1975."

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Contents

MODIFICATIONS

Pages 1- 13 of this publication has (have) been deleted in adapting this material for inclusion in the "Trial Implementation of a Model System to Provide Military Curriculum Materials for Use in Vocational and Technical Education." Deleted material involves extensive use of military forms, procedures, systems, etc. and was not considered appropriate for use in vocational and technical education.

Flight Line Safety for the Electrician

STOP AND THINK for a minute. When did you first learn about safety? Your mother was probably your first safety instructor. She taught you not to chew on the lamp cord, not to touch the hot stove, and many, many other "nots." As a child she wouldn't let you play in the street, or she would yell, "get down from that tree before you fall and hurt yourself." As you grew older your father probably started teaching you how to do things correctly and safely. In addition to your father, you heard safety from the teachers in school. If you stop to think about it, you will probably hear about safety for the rest of your life. While you are in the Air Force, your safety instructors include the people from the safety office, your supervisor, co-workers, signs, lectures, procedures listed in TOs and manuals, and this chapter.

2. Instructors alone cannot and will not prevent you from having an accident. Only thinking can prevent accidents and this thinking must come from you. What thinking?—You must THINK and PRACTICE safety at all times. You must think about safety to the point that it becomes an automatic reaction. When you reach this objective, you become safety conscious and take positive action toward safety.

3. There are some people who refuse to take positive action toward safety. It shows up in personal habits that allow them to perform unsafe acts, disregarding the safety of others. We allow these people an excuse by saying they are "accident prone." One such person is "Al Lectric." He is classified as "an accident looking for a place to happen."

4. Throughout this CDC you will see cartoons of Al doing what comes naturally, not following prescribed safety procedures. You may think Al is a figment of someone's imagination. He is real. Look around at some of your fellow workers; you'll see him in action. Don't forget to look at yourself. There is a little of Al in everyone. He appears whenever we show disregard for safety.

5. In this chapter and throughout the CDC we will discuss safety and you. We will point out some of the high accident rate areas where you will be required to work. The areas that we discuss are areas where accidents have happened to others. When it comes to accidents it is less painful to learn from the mistakes of others. Don't become an accident statistic; THINK.

3. Flight Line Safety

3-1. There are two major areas of concern on the flight line; these are "Al Lectric" and aircraft. Al can pop up any place so we will concentrate on aircraft and let Al come in at his leisure. Really, we would like for him to retire, and I'm sure you will agree after you have had to deal with him.

3-2. Aircraft, as you know, come in assorted types and sizes. We will discuss the types (with reference to power plant) such as reciprocating and turboprop, jets and helicopters. Size!!!! Just remember that any of them are big enough to kill you. There are danger areas around all of them and these areas concern you. Let's find out where they are and learn to respect them.

3-3. **Operating Aircraft Engines.** Aircraft engines that are not running cause little if any hazards to safety. However, they were not designed to sit still but to propel aircraft either on the ground or in flight. All engines have areas that are dangerous, so let's discuss them briefly.

3-4. *Reciprocating and turboprop engines.* To some, propeller-(prop) driven aircraft may seem outdated. Nevertheless, we have to work around them. There is one area that you need to stay clear of and that is the propeller. Now people like Al walk through the "prop" blades when the aircraft is in the dock. This may seem harmless, but habits are formed this way, and one day Al tries it on the flight line. What happens?—Nothing much—except Al now has a permanent part in his hair. It even reaches his belt buckle. What are we saying?—Props have no regard for

Cartoon 1. AL—Ground Safety Office.

rank or anything else, as figure 6 indicates. Treat them as though they are turning at 1000 rpm all the time and you will be safe. The next aircraft mentioned is the jet.

3-5. *Jet-powered aircraft.* These aircraft make up our bomber and fighter forces in most cases. Again the engine of this aircraft is to be respected. It is the biggest vacuum sweeper you have ever seen. Everything from safety wire to human beings have been sucked into jet engines. Figure 7 indicates that 25 feet is a minimum safe distance around the intake. Now, you may be a big man but you don't fight turbine blades even at idle speeds. You can't WIN, so STAY CLEAR of the INTAKE.

3-6. There is more than this about a jet engine. The exhaust will require a wide berth. A good rule of the thumb is to stay at least 200 feet behind any jet engine. For best results check the maintenance manual for the danger areas that apply to the aircraft you work on. Figure 7 illustrates the warning areas.

3-7. Before we leave the jet engine there is one more thing that is worthy of mention—noise. You have heard it, I'm sure. If you haven't, then you might take a trip to the flight surgeon's section to find out why you haven't. Take it from those who now wear hearing aids, the best place for your ear plugs is in your ears. Especially when you are on the flight line around noisy equipment. Make sure your ear plugs fit, and use them.

3-8. One word of caution about ear plugs. When you wear them, watch where you walk. Why should you?—What if that engine is running?—Be sure the engine is not running before entering a danger area.

3-9. Each type aircraft has its own peculiarities. The helicopter is definitely a good example of this. Let's discuss it now.

3-10. *The helicopter.* This aircraft can be powered by either a reciprocating or a jet engine. The helicopter is sometimes referred to as a rotary wing aircraft. These wings that provide lift for flight are called rotor blades and are driven by the engine. You must be aware of the danger areas formed by these rotors. There are certain places within the rotor path that will

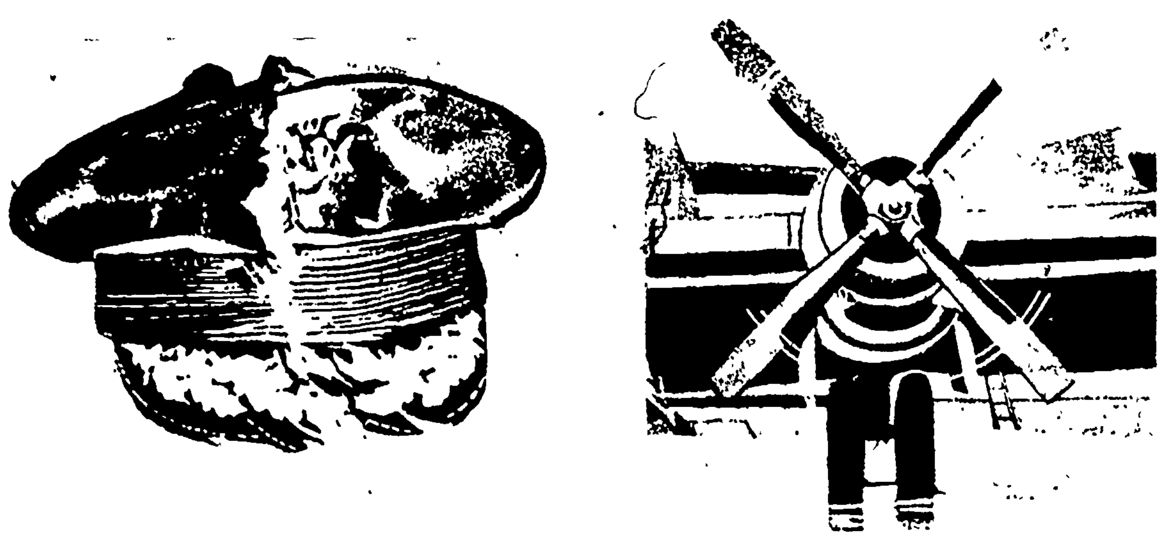

Figure 6. Crushed hat—prop area.

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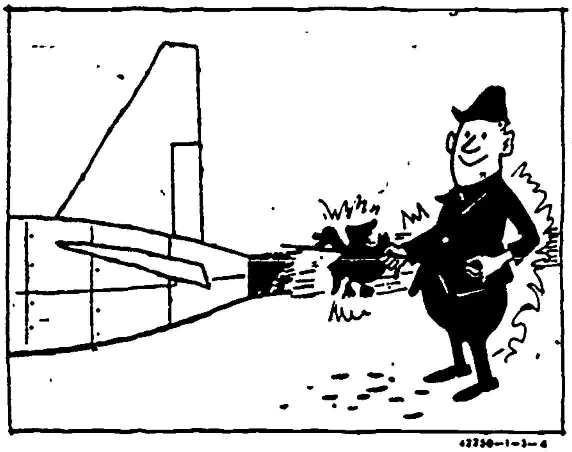

Cartoon 2. AL—Roasting a Duck.

allow you to approach the fuselage of the aircraft with the rotors turning. You need to know these areas before you attempt to enter the rotor path. Each type helicopter is different, so refer to the technical order for the helicopter you might be around. Air Force regulations say that your hair must be neat and trimmed at all times, but not "rotor trimmed." Support your base barber and avoid the rotor path.

3-11. Now let's discuss some areas and operations that are common to all types of aircraft. These may differ slightly with a particular aircraft but we will keep them general enough to cover any job you may be assigned.

3-12. **The Cockpit.** Another area that people like Al Lectric need to avoid is the cockpit. You see, Al has a disease known as "switchitis." You won't find this word in the dictionary. It is a term that describes a person who just *has* to turn every switch he sees to the ON position.

3-13. The modern aircraft cockpit, like a gun, is deadly in the hands of the inexperienced. Located in the cockpit are the controls for explosives, wingtip tanks, canopies, ejection seats, flap controls, and landing gear controls, all of which are killers. Learn the cockpit details of all the aircraft on which you are required to work. Be able to recognize nonstandard equipment. Know exactly what each switch or lever does. Use caution so that you do not accidentally lean or brush against any handles, switches, or levers. Never pull a handle or flip a switch if you do not know what the results will be. You may be in for an unexpected ride. If you don't know what you are doing, don't do it. THINK AND LIVE.

3-14. Be aware of other people working on the aircraft. Especially if electrical or pneudraulic power is applied. If you accidentally hit the wrong switch at the wrong time, someone could be seriously hurt. Many times you will be required to work on the aircraft with power applied. On some of these occasions, you may not want power on your system. If this be the case, pull the circuit breaker. Don't stop there, though. Tag it so no one will reset it. By doing this you could prevent a shocking situation from happening—to you. One last word before you climb out of the cockpit. If you ever feel "switchitis" coming on, get out, and do it the right way.

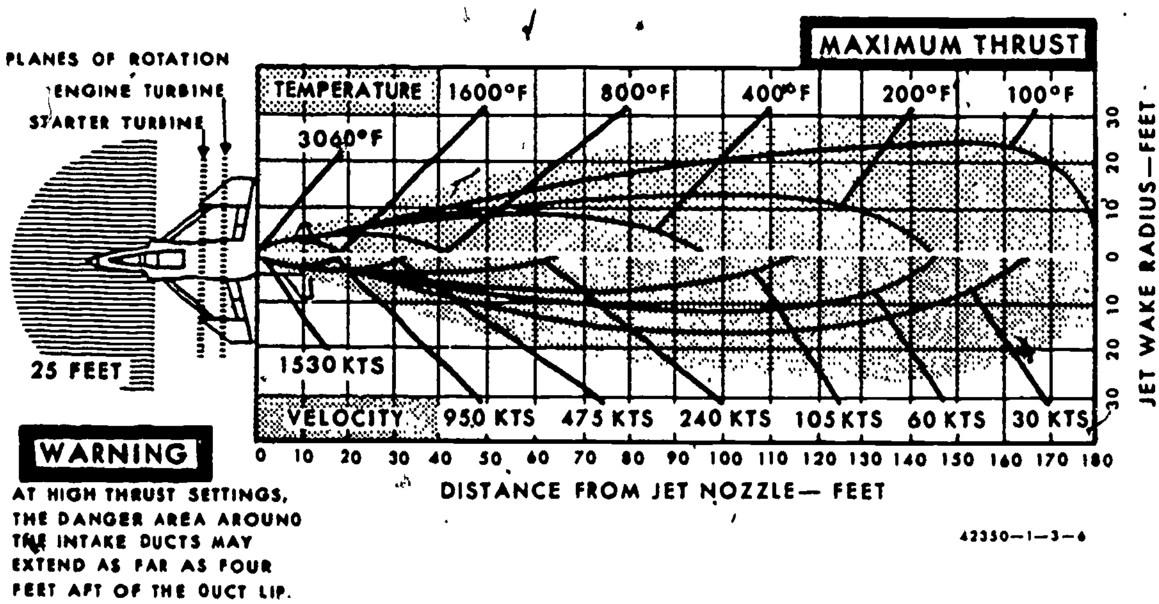

Figure 7. Danger area around jet engine.

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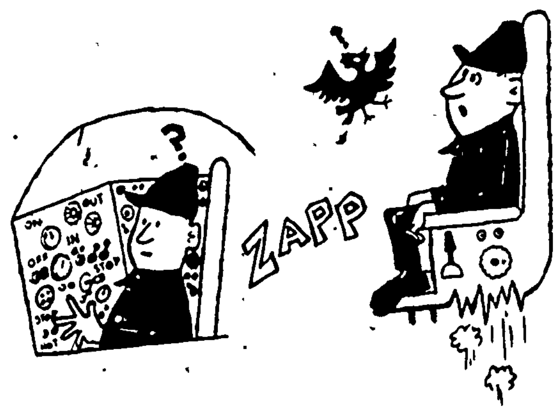

Cartoon 3. AL—Switchitis.

3-15. We mentioned electrical and pneudraulic power earlier, now we need to discuss them further.

3-16. **Electrical and Pneudraulic Power.** Pneudraulically operated and electrically controlled systems are common to modern aircraft. Thus, you will need to know these systems and the danger areas around them. Some of these systems are speed brakes, bomb doors, missile bay doors and landing gear doors. Most of these doors move their full span of travel in seconds, and work under pressure up to 3000 psi. If you like your head, hands, legs, and feet, I would highly recommend that you keep them out of these areas. That joker with "switchitis" just might be in the cockpit. In fact, check for safety pins or locks if you work in one of these areas. What am I saying?—Use your head, DON'T LOSE IT. You may be wondering how landing gear doors can work when the aircraft is on the ground. This will be our next point of discussion, working around an aircraft on jacks.

3-17. **Aircraft on Jacks.** This is definitely a time when the brain must be engaged. An aircraft on jacks is unstable at best. You will have occasion to work on landing gear problems while the aircraft is on jacks. When this time comes there are some things you don't do and live to brag about them. Stay clear of the wheel wells and landing gear doors. In fact, if you don't need to get under the aircraft, stay out.

3-18. When jacks are used a man is in the cockpit and he has direct communication with someone on the ground. No one tries to talk above flight line noise; you use an interphone (headset). The man on the ground is in position to see every area around the aircraft. Unless there is a definite reason, no one should climb on the aircraft while it is on jacks. It gets embarrassing when you have to explain how a jack went through the wing of a multimillion-dollar aircraft. It also causes a terrible headache if that wing hits someone on the head, as it slips off the jack. Make sure the right jack is used and check its condition, also. All aircraft jacks have safety locks. Be sure they are used. You may think part of the things mentioned here aren't

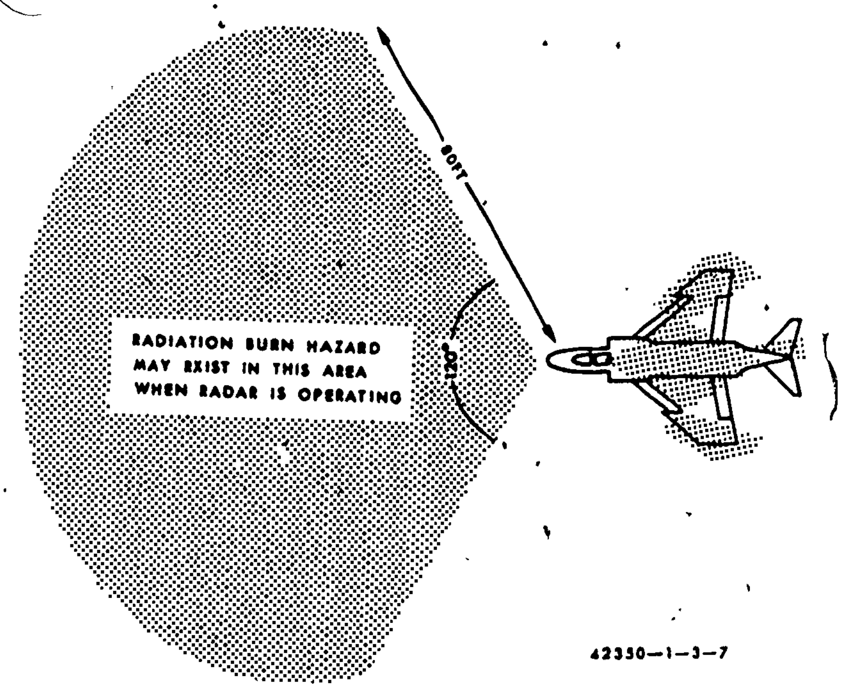

Figure 8. Radar danger area.

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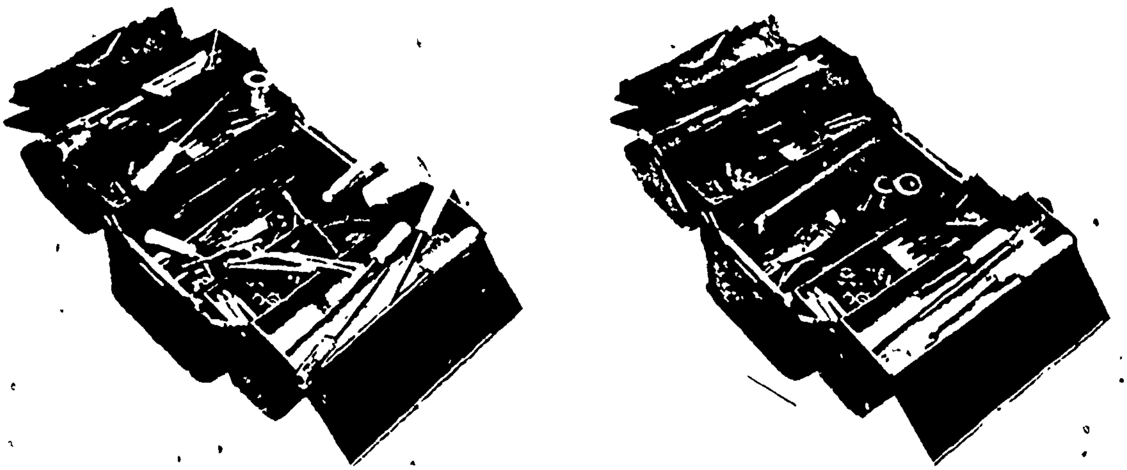

Figure 9. Toolbox.

your responsibility. If this be the case, just remember, it could be your head that is squashed.

3-19. **Radar Equipment.** Up to this point, we have discussed things that you could either see, smell, hear, or feel. Now let us discuss some equipment that can cause many unseen ill effects on the human body. This is the radar system. Dry steel wool can be ignited at 100 feet and photoflash bulbs have been fired at greater distances. With this in mind, think what might happen to you if you are exposed to these radar beams. AC at frequencies in excess of 10 KC can no longer be felt but they leave lasting results on the human body. Exposure to radar beams can damage human tissue, particularly the eyes. For your own protection stay clear of operating radar equipment. Check the maintenance manual for the aircraft on which you are working, it will give you the danger areas. Figure 8 gives you a general idea of the areas to shun.

3-20. **Radioacitve Material.** Nuclear radiation (atomic) is probably the least likely hazard to be encountered on the flight line. It might exist, however, in the event an accident should occur while handling one of these weapons or if an aircraft carrying one of them should crash. Then, too, we might be required to perform maintenance on an aircraft that has been in a contaminated zone. We should know what to expect if this occasion occurs.

3-21. Radiation, basically, consists of tiny energy particles that can kill you if you are exposed to a sufficient quantity for too great a period of time. Therefore, you will work under the supervision of medical personnel and a monitoring team. Let me remind you, though, your responsibility to yourself and to the Air Force requires that you stay abreast of the latest information concerning radioactive material. This information can be found in the applicable technical orders.

3-22. By this time, you have probably decided it isn't safe at all on the flight line. Let's put it this way, any place you may happen to be is only as safe as you make it.

3-23. This brings us to another point of discussion. When you mention good housekeeping, a person may remember his mother and her job as a housewife. If you remember right, Mom had a place for everything and she wanted everything in its place. Let's see how this fits you and your job in the flight line area.

4. Good Housekeeping and Fire Prevention

4-1. It has been truly said that "cleanliness is next to godliness." Good housekeeping is the neatness and cleanliness that is necessary for the successful performance of a job. It is also much easier to prevent a fire than to stop one after it has started. In the following discussion we will cover the points for which you are responsible in both areas.

4-2. **Good Housekeeping.** A major principle to observe in maintaining a working environment conductive to safety is good *housekeeping*. Having found it advantageous to live in a well-kept household, you will also find it desirable where you work.

4-3. One of the elements of good housekeeping is the disposal of waste and scrap. If floors or workbenches are cluttered by such material, the chance for an accident is increased.

4-4. As an example, some of the units that you will be required to disassemble will have small parts which can be easily lost, broken, or mixed with other parts. To avoid the loss of time while you hunt or acquire another part, keep

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your bench top neat and in an orderly condition. A cluttered bench makes effective work almost impossible and is the starting place for an accident. Worn out or irreparable parts should be disposed of promptly and put in the right places, not on the floor.

4-5. A quick glance at the way tools are arranged in a toolbox is one way to measure a good mechanic. Look at figure 9. I am certain the one on the right is yours! Every shop has a designated place for toolboxes when they are not in use. Keep them in place and keep the lid closed. It does not require much time or effort to open the box when you need a tool, and you may prevent someone from acquiring a badly bruised shin. Most shops will have a tool board to make special tools available to all who may need them. Keep them in place. Since some of these tools are quite heavy, get help or use a chain hoist if necessary to put them in place.

4-6. If your shop maintains a stockroom, cases and other goods should be stacked neatly in the prescribed location according to the designated height. This will prevent possible damage to the stored items and will also make them readily available.

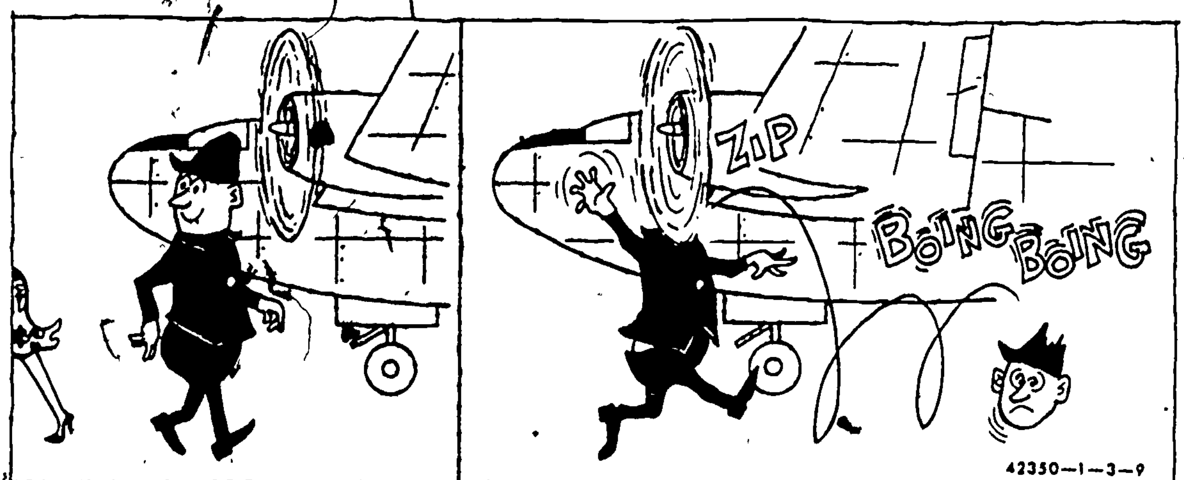
4-7. Good ventilation is conducive to good work and necessary for the good health and safety of personnel. You will find that your work output drops off considerably if you are uncomfortably hot or cold, or if there is a lack of fresh air. If the air is dusty in your shop, or if fumes are present, tell your supervisor or trainer. When he is aware of the conditions under which you work, he can take the necessary corrective action.

4-8. **Fire Prevention.** Closely allied with good housekeeping and absolutely necessary for any organization is a smooth working fire prevention system. Remember, the best cure for any fire is to prevent it by safety precautions. If a fire occurs, however, be prepared to put it out quickly.

4-9. Many fires are caused by carelessness and by poor housekeeping. Oily rags thrown in a corner are excellent material for a healthy fire. Poor storage practices, especially of inflammable materials have caused fires that need not have been. Overloaded electrical outlets coupled with defective circuit breakers may also cause a fire. Observe also that no smoking signs were made to be obeyed; lighted cigarettes or matches thrown in wastepaper baskets full of paper are not usually put out by the fall. Here are a few precautions that you should observe for fire prevention; you can add to the list from your own experiences or from warnings that you have read or heard.

- Do not allow oily rags to accumulate.
- Obey the signs in the NO SMOKING areas.
- Never allow your clothing to become saturated with fuel or oil. If they should become that way accidentally, change your clothing as soon as it is possible.
- Do not permit gasoline, kerosene, jet fuel, or any other inflammable fuels to be stored in open containers.
- Make sure that the static lines are always in place and that the aircraft is grounded properly before you work on it.
- Never deposit cigarettes or matches in a wastebasket, even if they appear to be out.
- Do not open any oxygen valve near a flame or a lighted cigarette.

4-10. Since fires will occur, no matter how many precautions taken, you must be ready to



Cartoon 4. AL—Loses His Head.

fight them quickly and effectively. This implies that you should know the telephone number of the base fire department and the location of the fire extinguishers.

4-11. The telephone number for the base fire department is usually posted in large numbers. These posters are at intervals in the shop, in the barracks, and on the flight line. As a rule, the base telephone book has this number printed in large letters on the cover page or on one of the first pages of the book. If alarm boxes are installed on your base, learn where they are and how to use them.

4-12. As you can see, safety is everyone's responsibility; this includes you. One of the main motivating factors is that YOUR LIFE is involved. I have heard people say, "I'll be glad to get out of this outfit, all they think about is safety." We will be involved in safety as long as we live. In fact, our life span may be in direct proportion to how serious we take the safety program. An old Chinese proverb says, "Be sure brain is engaged before opening mouth." We can apply this to safety. "Be sure brain is engaged before acting or!!!!!!!! What am I saying?—It's your head, just where do you want it?

18

Major Aircraft Systems and Electrical Maintenance and Inspection

AS AN AIRCRAFT electrician, you will become involved in the "electrical repair" of different types of USAF aircraft. In fact, you may find yourself working on several types within one day's time. Therefore, you will need to be familiar with all of the aircraft in the Air Force inventory. Sounds like a big job, huh?—And you're right, it is. In this chapter we discuss many of the things that put you out front, so dig in and learn.

2. In the first section, the discussion will center on aircraft types, distinguishing characteristics, and aircraft designations. Another section will discuss aerodynamics and flight controls. Don't let that 12-letter word in the last sentence scare you. This is just another way of referring to all the forces that act on an aircraft in flight. This is followed by a discussion of the major aircraft systems.

3. After discussing what you work on, we discuss what you work with. In doing this, we consider such things as aircraft servicing materials, electrical hardware, and handtools that are peculiar to the electrical field. The final discussion in the chapter will cover electrical system inspections and their importance. Now let's discuss aircraft familiarization.

5. Aircraft Familiarization

5-1. Each year many people rush down to the new car dealer to see what the new models look like. They want to know what equipment is standard and what is optional. They look for any detail that can help them fix this new model in their mind. The aircraft electrician that plans to be counted with the best must have the same attitude toward aircraft. Does this include you? I'm sure it does so we will start our discussion with the types of aircraft.

5-2. **Types of Aircraft.** Today's Air Force has many missions to perform. Each mission requires a special type aircraft, one that is specifically designed to meet mission needs. Space prohibits a discussion of individual aircraft; therefore, we will discuss major aircraft types.

5-3. *Bomber.* These aircraft are equipped with powerful jet engines, and carries a bomb load comparable to its mission. Some can fly faster than the speed of sound and at very high altitudes. These might be referred to as medium-range bombers. Some have provisions for in-flight refueling, thus giving them long-range flight capabilities.

5-4. *Fighter.* These aircraft can be powered with either a radial or jet engine. Most of them, however, are jet. Fighters are used to engage the enemy in the air and on the ground. To accomplish this mission, they must be fast, maneuverable, and carry heavy fire power. The latest type fighters can perform at supersonic speeds. Their fire power may consist of rapid fire machine guns, cannons, or rockets that are equipped with homing devices. Some have in-flight refueling capabilities for long-range missions.

5-5. *Transport.* This aircraft is sometimes referred to as a cargo plane and is just the opposite to the fast-moving bomber or fighter. Transports are sturdy, relatively slow flying, with the capability to carry heavy loads over long distances. Their wings are usually thick, with a fuselage large enough to allow loading of heavy freight and vehicles.

5-6. *Helicopter.* This aircraft is unfamiliar to many people. However, to the jet fighter who has been downed in enemy territory, it is a beautiful sight to see the "ole chopper" hovering over him. This aircraft is the most versatile type made. It can fly in any direction without changing its compass heading. In the Air Force helicopters are primarily used for search and rescue. Some,

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Figure 10. Conventional-wing aircraft.

however, have firefighting capabilities, and other branches of the military use them as cargo and gunships.

5-7. The helicopter is easy to recognize because of its relative slow speed and whirling rotor blades. However, you only get a glimpse of some of the others mentioned, so we need to discuss their distinguishing characteristics.

5-8. **Distinguishing Characteristics.** The design of the wing is one of the most prominent features of an aircraft. You will find that it is much easier to recognize all types of aircraft if you are aware of the basic wing design. From the following discussion you will see that the wing design will vary with the mission of the aircraft.

5-9. *Conventional Wing*. Many types of aircraft have the conventional wing. Since the construction is similar in all conventional types, we shall discuss only one of these aircraft, the C–131. The C–131 has a low-mounted wing that is equitapered and blunt tipped, as shown in figure 10. The large engine nacelles protrude well forward of the wing's leading edge. The rounded nose and a stepped-up cockpit are features of the forward fuselage, while the aft fuselage tapers evenly to a pointed tail cone. Both horizontal and vertical stabilizers are equitapered and blunt tipped.

5-10. *Swept Wing*. Bombers and fighters usually have swept-wing type construction. The B–52 is an example of a sweptback wing that is very noticeable. The aircraft is powered by eight jet engines, as shown in figure 11. These engines, two in a pod, are slung under the wings on short pylons. The large horizontal stabilizer is also sweptback and tapered with a squared-off tip that emphasizes the overall angularity. This overall angularity and the large size are the B–52's most distinguishing features.

5-11. *Delta Wing*. Another wing type aircraft is the B–58. The wing has a delta-shaped design that curves downward at the leading edge. This curve increases near the tips, which gives the wing an apparent droop appearance. The B–58's

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Figure 11. Swept-wing aircraft.

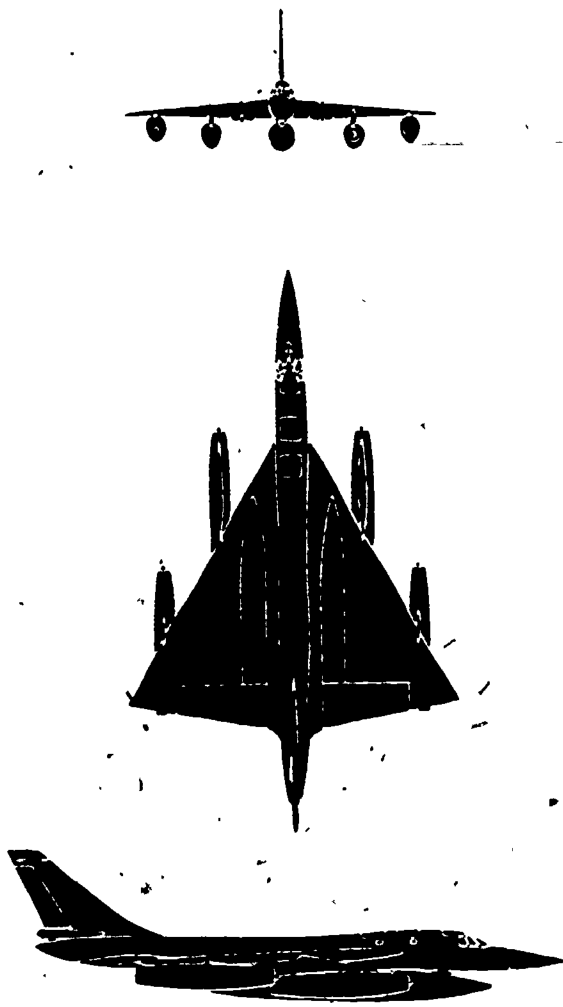

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Figure 12. Delta-wing aircraft.

four engines are inclosed in pods. They are slung under the wings and are staggered well forward of the wing's leading edge, as shown in figure 12. The large hump on the topside of the extremely slender fuselage is caused by the three separate cockpit hatches. This kind of fuselage is sharply pointed at the nose and tail cone. The use of a horizontal stabilizer is eliminated by having "elevons" in the delta wing's trailing edge. These "elevons" do the combined work of the elevator and aileron. All of these will be covered in a later paragraph.

5-12. Just as you have an I.D. or serial number, so does each aircraft in the Air Force. A quick look at how aircraft are identified, other than just construction features, is in order at this time.

5-13. **Aircraft Designations.** The various types of aircraft used by the Air Force are identified by a combination of letters and numbers called aircraft designations. Each letter and number, or combination of letters and numbers, indicates important information about a particular aircraft. Thus aircraft designation identifies each aircraft, as well as its mission, using the letter and number system. An example of this would be RB66B, 53–412. This aircraft was originally designated as a bomber, but what does each letter and number tell us about it?

- R - Reconnaissance. This indicates the current use of the aircraft. It also (in this case) indicates that the original design has been modified.
- B - Bomber. This indicates original mission-design of aircraft and normally would be the first letter of designation.
- 66 - Aircraft model number, meaning the number of bombers the Air Force has tested for its mission.
- B - Series of the basic aircraft. In this case, it indicates the first modification of the basic series.
- 53 - Fiscal year that procurement for this aircraft was authorized.
- 412 - Serial number. This does not indicate the number of aircraft manufactured, but is an Air Force assigned number.

5-14. A complete coverage for aircraft designation is located in AFR 66–11. However, the previous example gives enough information for you to figure out all the common designations.

6. Aerodynamics and Flight Control

6-1. Now that you have a good idea what aircraft in general look like, we will discuss what makes them fly. You, as an electrician, will be

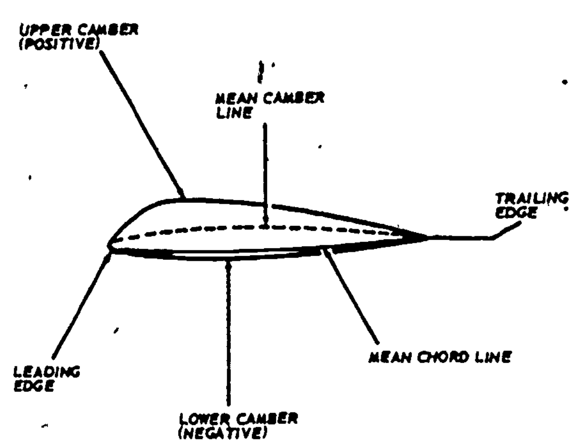

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Figure 13. Typical airfoil.

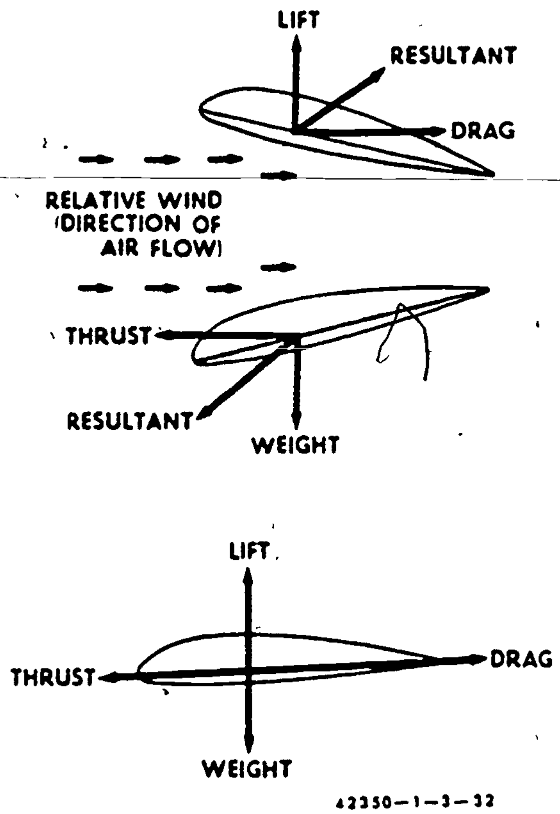

Figure 14. Four forces acting on the airfoil.

required to maintain the trim system that trims an aircraft around its three axes. Therefore, you must be able to fly the aircraft mentally even though not physically. For example, what does the pilot mean by experiencing a nose-heavy condition throughout flight? What system would you adjust to correct this trouble? Let's see if we can answer these two questions.

6-2. **Principles of Flight.** In order for you to better understand your job, it is necessary that you have a good fundamental background of the principles of flight. No doubt, man got the idea of flight from watching the birds soar gracefully overhead. His early attempts at flight, for the most part, were fantastic, and often fatal. It boils down to the fact that man, in his early attempts, didn't know enough about aerodynamics. First, let us review the characteristics of an airfoil and the forces acting upon it in flight.

6-3. *Airfoils*. Figure 13 illustrates a typical airfoil. You will note that the two ends of the airfoil differ in appearance. The end that faces into the wind in flight is called the leading edge and is rounded, while the other end, the trailing edge, is tapered and narrow. A reference line often used in discussing an airfoil is the *chord,* a straight line drawn through the airfoil connecting the farthermost points of the leading and trailing edges. The distance from this chord line to the upper and lower surfaces denotes the amount of upper and lower camber (curvature).

6-4. *Aerodynamic forces*. With an understanding of the structure of an airfoil, let us take up the four aerodynamic forces acting upon an aircraft. These forces are lift, drag, weight, and thrust. The *lift* of the airfoil acts perpendicular to the direction of the relative wind. The *weight* (or gravity) acts vertically downward from the center of gravity of the aircraft. *Thrust* is the force which moves the aircraft forward during flight, and *drag* is the resistance of the atmosphere to the aircraft's forward motion. When the aircraft is in a level unaccelerated flight, the lift equals the force of gravity, and the thrust is equal to the force of drag.

6-5. Figure 14 illustrates how the four forces that determine flight actually cancel each other. The upper view shows two forces, lift and drag. At the same time that the lift force pulls the airfoil up, the resistance of the airfoil (drag) pulls the wing backward. The resultant action, consequently, is not just a straight backward motion; it is a combination of both. In the center view, the other two forces—thrust and weight—cause the airfoil to have just the opposite movement. The thrust causes the airfoil to move forward, but the weight (gravitation pull) causes the airfoil to fall toward the earth. The resultant airfoil motion is a combination of these two motions; it is forward and downward. Putting these forces together produces the motion shown in the bottom view of figure 14. As you will note, the forces act in different directions and cancel each other. If the force of lift is as great as weight, the airfoil neither rises nor falls (climbs or dives). If the thrust is as great as the force of drag, the airfoil does not move either faster or slower but moves at a constant speed. To go faster, we merely increase the thrust over drag and the aircraft accelerates. Then, when the thrust and drag again equalize, the aircraft no longer accelerates, but moves ahead at a faster constant speed.

6-6. While we are reviewing the principles of flight, we will consider two laws which combine to make it possible for an airfoil to support (lift) a heavy weight in air. The first law can best be illustrated by holding your hand out of the window of a moving automobile. As you incline your hand, the force of the air against your hand has a tendency to move it. The airfoil (your hand in this case) deflects the wind. This action creates a dynamic pressure on the lower surface of your hand, forcing it upward

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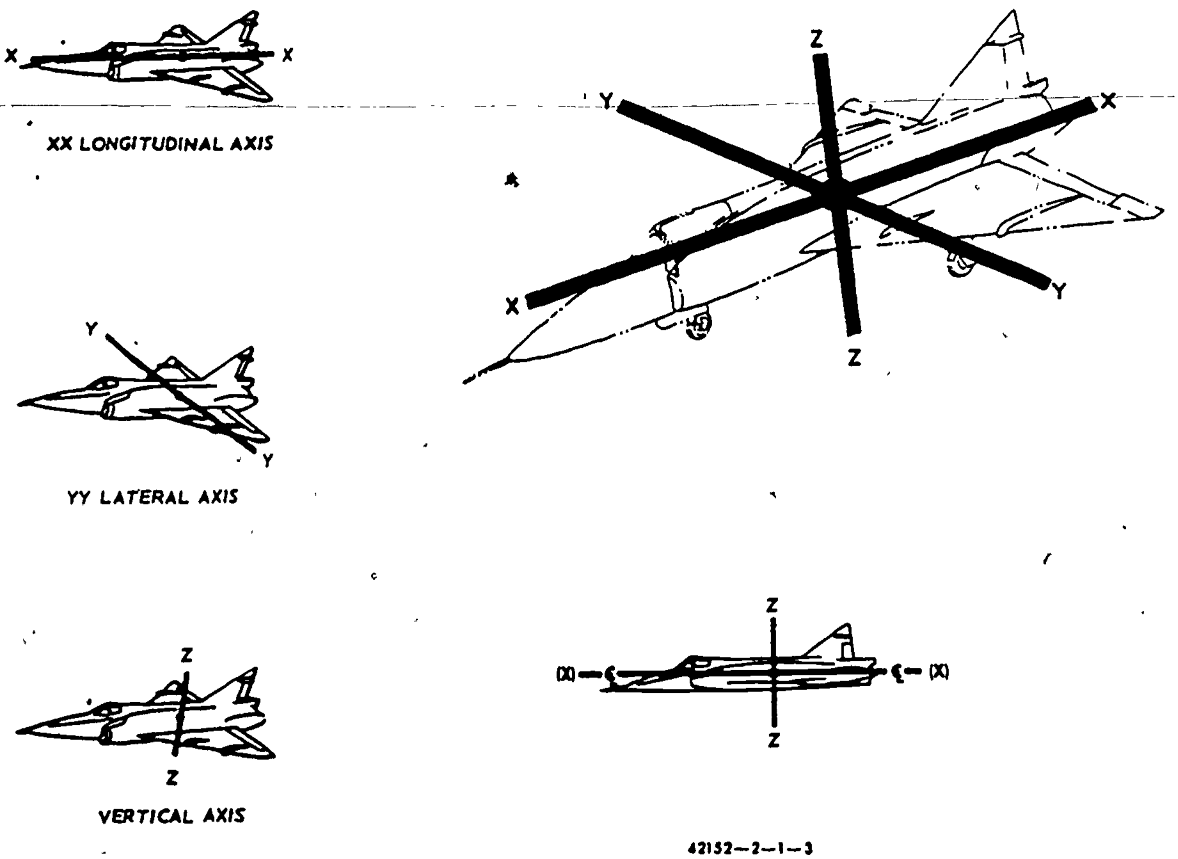

Figure 15. Axes of the aircraft.

and backward. The second law is that of the Venturi tube principle. When an airfoil moves through the air, both the airfoil shape and the airfoil angle of attack relative to the wind cause the air to be deflected. The deflection compresses the air below the airfoil, which causes a high pressure area under the surface. The air traveling across the upper surface of the airfoil must travel a longer distance, which, consequently, causes the speed of the air across the upper surface to increase. This increase in velocity of the air produces an area of low pressure next to the upper surface of the airfoil. In this manner a pressure differential is created.

6-7. The difference in air pressure between the bottom and top of the airfoil gives the lift. As the speed of the airflow increases, the pressure differential acting on the airfoil also increases. As already mentioned, drag is the resistance of the atmosphere to the aircraft's forward motion, and the drag will always act parallel to the relative wind.

6-8. The relative wind is the direction of the airflow with respect to the airfoil. If an airfoil is moving forward horizontally, the relative wind moves rearward horizontally. If the airfoil is moving forward and downward, the relative wind moves rearward and upward. The angle of attack of an airfoil directly controls the distribution of pressure above and below it.

6-9. The angle of attack can be defined as the angle between the chord of an airfoil and the direction of the relative wind. Actually, you could not continue to travel in level flight and maintain the same angle of attack if you increased your airspeed; the airfoil lift would increase and the aircraft would climb. For each angle of attack, each aircraft has a definite speed at which it will fly straight and level. To maintain the constant lift force which balances the weight in straight and level flight, the airfoil velocity must be decreased as the angle of attack is increased.

6-10. Thus far we have discussed an aircraft ir straight and level flight; what happens if it turns? What happens if it climbs or dives? To what are these movements referenced? These are good questions, and the answers will help you become a better aircraft electrician.

6-11. *Aircraft flight axes.* There are three axes about which an aircraft may turn. Whenever an aircraft changes its attitude in flight in

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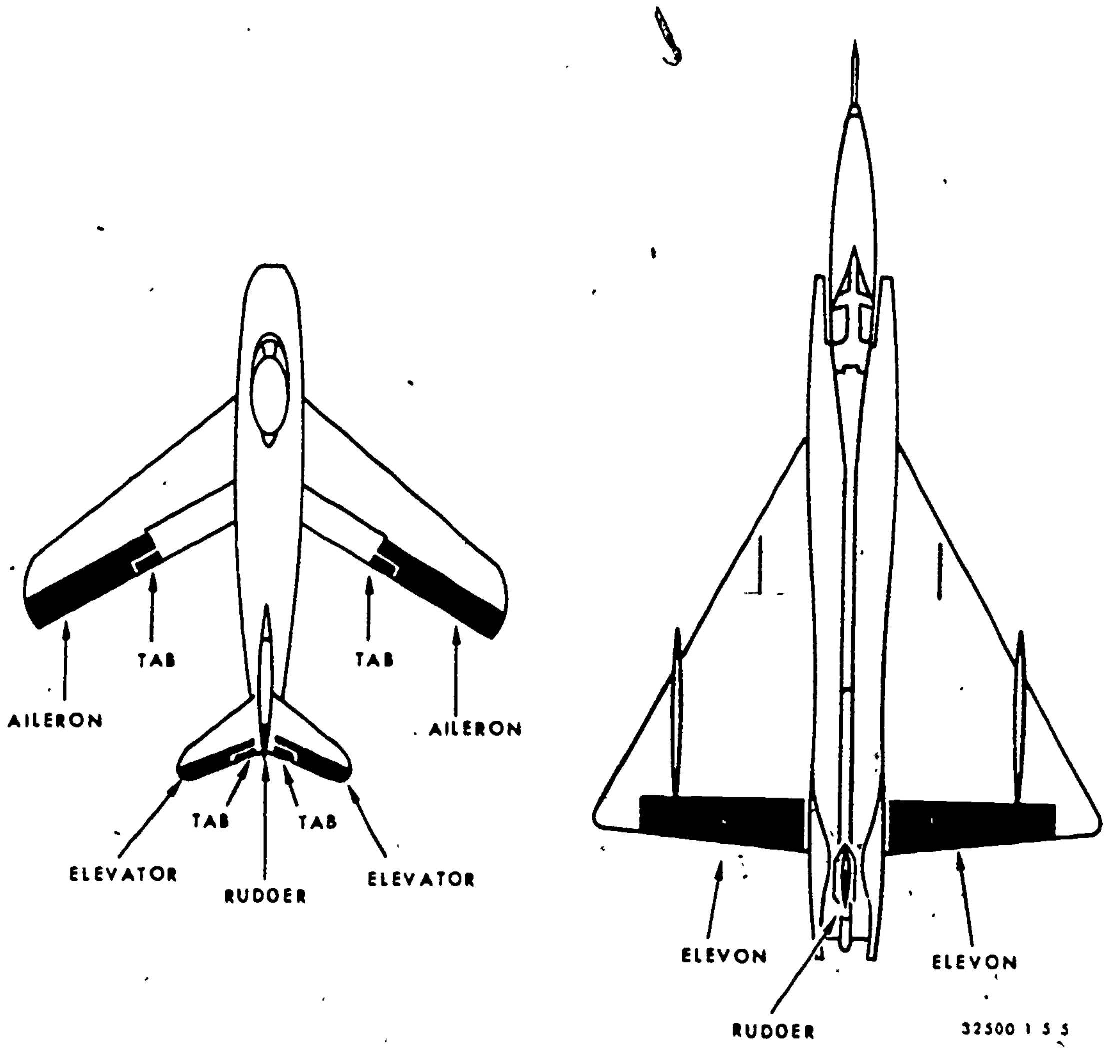

Figure 16. Flight control surfaces on an aircraft.

respect to the ground or any other fixed object, it must turn about one or more of its axes. These axes are imaginary lines passing through the aircraft's center of gravity. At the center of gravity each axis is perpendicular to the other two. Figure 15 illustrates the axes of the aircraft.

6-12. The longitudinal axis extends from the nose to the tail through the center of gravity. Movement around this axis is called roll. The lateral axis extends from wing tip to wing tip through the center of gravity, CG. Movement around this axis is called pitch. The vertical axis passes vertically through the CG and movement around this axis is called yaw.

6-13. The names roll, pitch, and yaw are used in describing the motion about an aircraft's axes. These were originally nautical terms. They have been adapted to aeronautical terminology because of the similarity of motion between an aircraft and a ship. Consequently, the motion about the longitudinal axis is called roll. Motion about the lateral axis is called pitch, which is similar to the pitching motion of a ship as it plows through a heavy sea. Finally, an aircraft moves about its vertical axis in a motion called yaw, deviating from its course in an angular motion such as you would use in sculling a boat.

6-14. What causes the aircraft to move around these axes? That is a good question. The next few paragraphs will answer it for you.

6-15. **Flight Control Surfaces.** When you drive an auto, I'm sure you know what happens as you turn the steering wheel. Do you know what happens when a pilot moves the control stick to the right? Can you picture in your mind what actually turns the aircraft to the right? To answer these questions, you must know the actions of control surfaces of the aircraft. To make these actions easier to understand let's break these surfaces into two categories, primary and secondary flight controls. These are shown in figure 16.

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6-16. *Primary flight control surfaces.* Roll, pitch, and yaw (the motions an aircraft makes around its longitudinal, lateral, and vertical axes) are controlled by the three main control surfaces. Roll is produced by the ailerons located on the trailing edge of the wings or by spoilers located on the upper surface of the wing. Pitch is effected by the elevators, the rear portion of the horizontal tail assembly. Yaw is controlled by movement of the rudder, the rear portion of the vertical tail assembly. You should remember that an aircraft often rotates about all three axes at the same time. You can see a good example of this when an aircraft accomplishes a climbing turn. Coordinated movements of ailerons or spoilers, elevators, and rudder cause the aircraft to make, in one turning movement, rotations about the longitudinal, lateral, and vertical axes. You must keep in mind that on some types of aircraft the elevators and ailerons are combined, and generally referred to as elevons. This is particularly true of delta-shaped-wing type aircraft.

6-17. The ailerons control the movement of the aircraft about the longitudinal axis. There are two ailerons, one at the outer trailing edge of each wing. Moving the control stick or wheel to lower the aileron on one wing raises the aileron on the other wing. The wing with the lowered aileron goes up because of its increased lift; the wing with the raised aileron goes down because of decreased lift. The movement of either aileron is aided by the simultaneous and opposite movement of the aileron on the other wing. When you apply pressure toward the right of the control stick, the left aileron goes down and the right aileron comes up, rolling the aircraft to the right. Down movement of the left aileron changes the wing camber and increases the angle of attack. The right aileron moves upward to change the camber; this results in a decreased angle of attack. Thus, decreased lift on the right wing and increased lift on the left wing causes a roll and results in a bank to the right.

6-18. Wing spoilers may be used to reduce speed or for control in place of ailerons. For example, in level flight, spoilers may be used as a speed brake to reduce speed for a high rate of descent or simply to slow down the aircraft. During landing, spoilers may be used to spoil effective extra lift created by the flaps so that landings can be accomplished on relatively short runways. Also, wing spoilers may take the place of ailerons. They may be moved individually, and cause one wing to go down because of its decreased lift, which results in a roll or turning of the aircraft on its lateral axis.

6-19. The elevators control aircraft movement about the lateral axis and produce the motion known as pitching. They may form the rear part of the wing assembly on delta-wing aircraft, or they may be part of the horizontal tail assembly and, thereby, free to move up and down. Like the ailerons which are fastened to the trailing edge of the wing, the elevators are also hinged to a fixed or movable surface horizontal stabilizer. On some aircraft, the horizontal stabilizer itself acts as an elevator. Together, the stabilizer and elevators form a single airfoil; and a change in position of the elevators changes the camber of the airfoil, increasing or decreasing the lift. Like the ailerons, the elevators are actuated through the control stick or wheel. Pushing the stick forward causes the elevators to go down. This action brings the tail up and the nose down, which causes a dive. Pulling the stick back causes the elevators to move up. This forces the tail downward and the nose upward into a climb.

6-20. The rudder controls the movement of the aircraft about its vertical axis and produces the motion known as yaw. The rudder is a movable surface hinged to the vertical stabilizer. Rudder action is very much like elevator action, except that it moves in a different plane. When the rudder is moved to one side, the shape of the airfoil is changed, producing a horizontal force opposite in direction to that of the rudder displacement. The primary purpose of the rudder is to give vertical stability to the aircraft and counter the effects of adverse yaw. Turning of the aircraft cannot be accomplished by the rudder alone. Displacement of the rudder by itself causes a flat skid. A coordinated turn is accomplished by banking the aircraft through the use of the ailerons or spoilers and the rudder. The amount of rudder displacement must be exact to prevent slipping or skidding during the turn.

6-21. *Secondary flight control surfaces.* The secondary control surfaces are the trim tabs, balance tabs, and servo tabs. These tabs are used to reduce the force required to actuate the primary control surfaces and for trimming and balancing the aircraft while in flight. These tabs are small airfoils attached to, or recessed into, the trailing edge of the primary control surfaces.

6-22. Sometimes an aircraft is loaded in such a way that it is slightly wing heavy, tail heavy, or nose heavy. To offset such unbalanced forces, the pilot would have to exert a constant pressure on the control stick or rudder pedals. To relieve this fatiguing effort, ailerons, elevators, and rudders are often provided with trim tabs.

6-23. Balancing tabs look like trim tabs and are hinged in approximately the same places as trim tabs. The main difference between the two

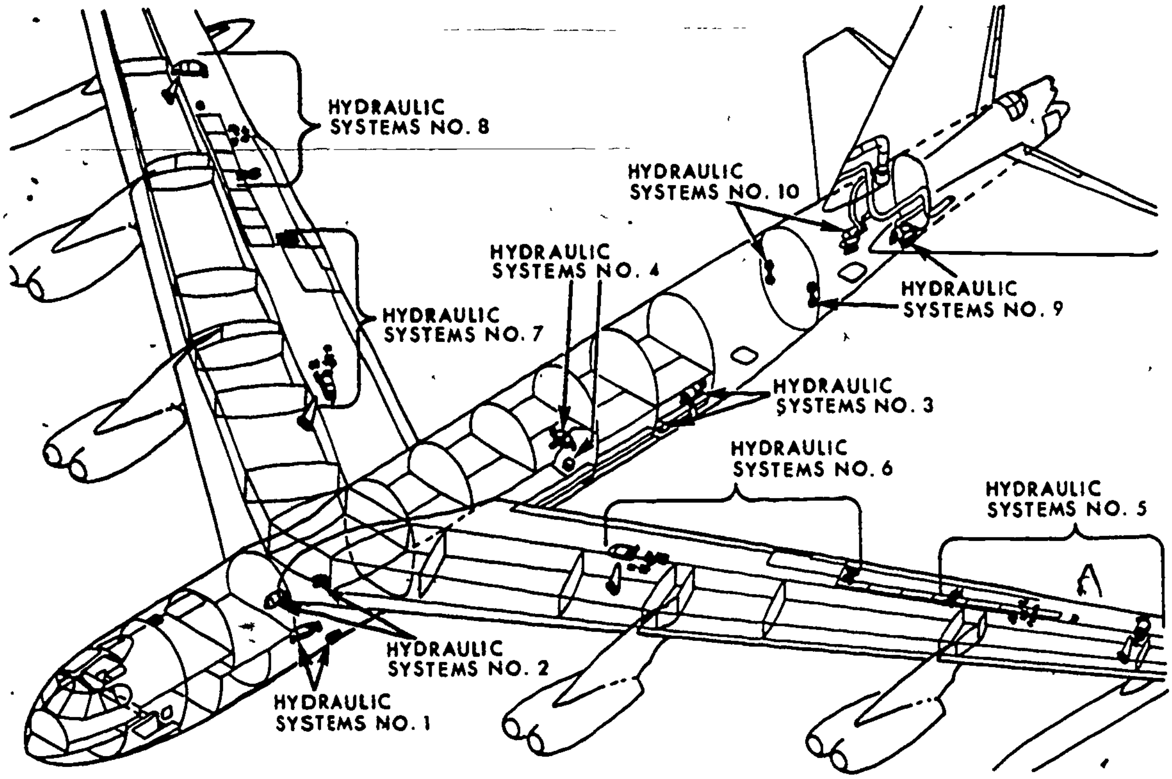

Figure 17. Hydraulic system pack location.

is that the balancing tab is connected to the airfoil in such a way that when the main control surface is moved in any direction, the tab is moved in the opposite direction. The airflow striking the tab counterbalances some of the pressure against the primary control surface and enables the pilot to move and hold it in position.

6-24. Servo tabs are used primarily on large airfoils to help the pilot move the heavy primary control surfaces. The tab control cables or rods are linked in a manner that allows the tab movement to precede the movement of the main control surface. This type of tab enables the pilot to move the controls with considerably less control pressure than is required in aircraft of comparable size and speed without servo tabs.

6-25. On late-model, high-performance aircraft, especially fighter type, all control surfaces are actuated through the use of hydraulic pressure. This eliminates the necessity for assisting the pilot in the movement of the control surfaces through the use of tabs. If trimming action is necessary, it is accomplished by movement of the complete control surface. The trim system is electrically actuated.

6-26. The location of flight control surfaces on conventional-winged and delta-winged aircraft is shown in figure 16. In the left view, note that tabs have been added to the control surface group. These tabs are used in the manner described earlier. The aircraft shown in the right view has only three control surfaces. The elevons have replaced the elevators and ailerons, but the rudder has remained the same in respect to function and location. The operation of flight control surfaces is the same on the many different types of aircraft in use.

6-27. We have reviewed the principles of flight, the effect the various control surfaces have on the flight of the aircraft, and how an aircraft is identified by a combination of letters and numbers. Now let's discuss the aircraft systems necessary for the safe flight of the aircraft.

7. Major Aircraft Systems

7-1. As an electrician, you should learn the location of the various components and equipment on an aircraft. These items are not discussed in any great detail in this section; however, by studying the applicable aircraft technical orders, you can become familiar with their locations. One of the major control systems is the hydraulic system.

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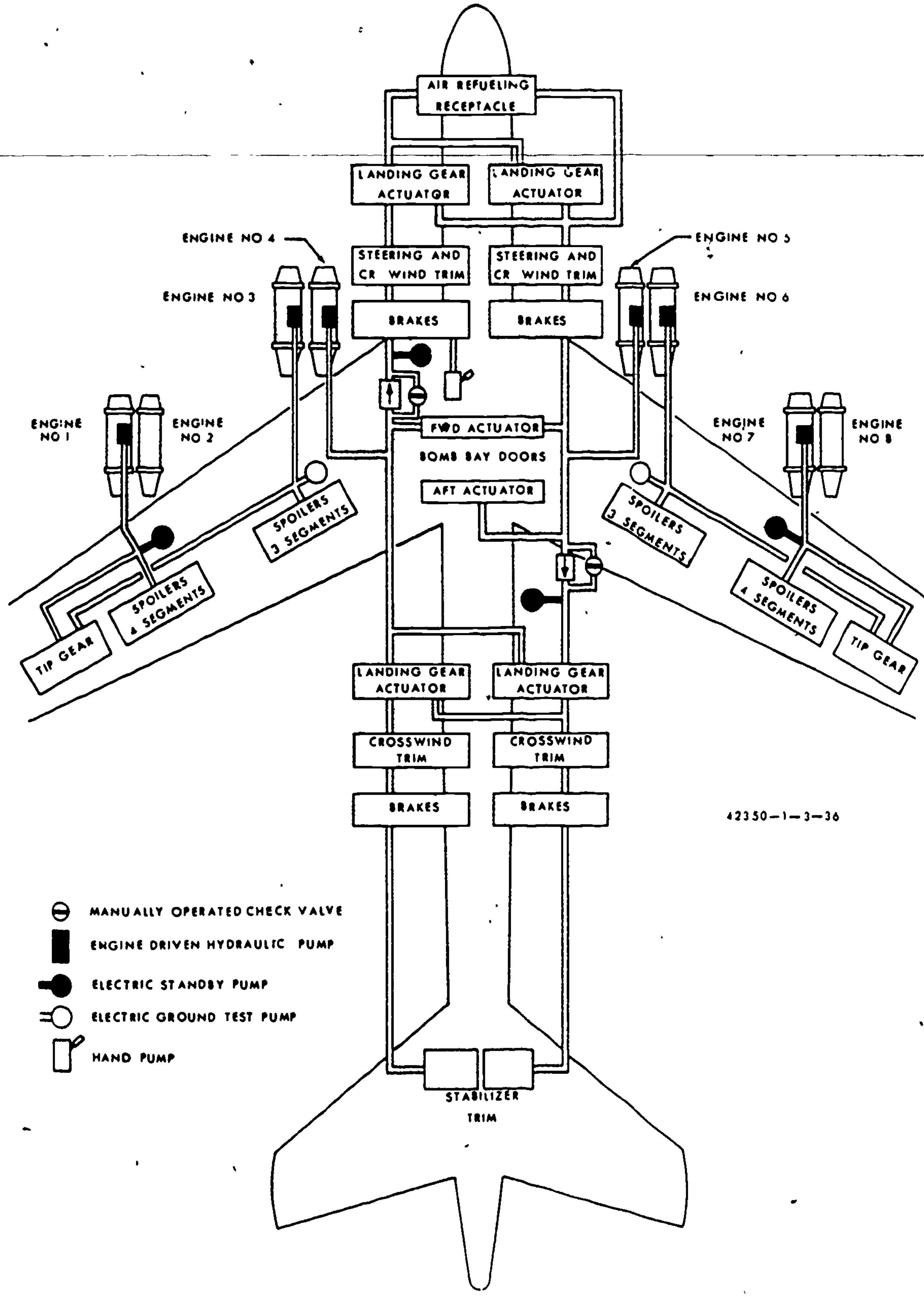

Figure 18. Hydraulically operated systems.

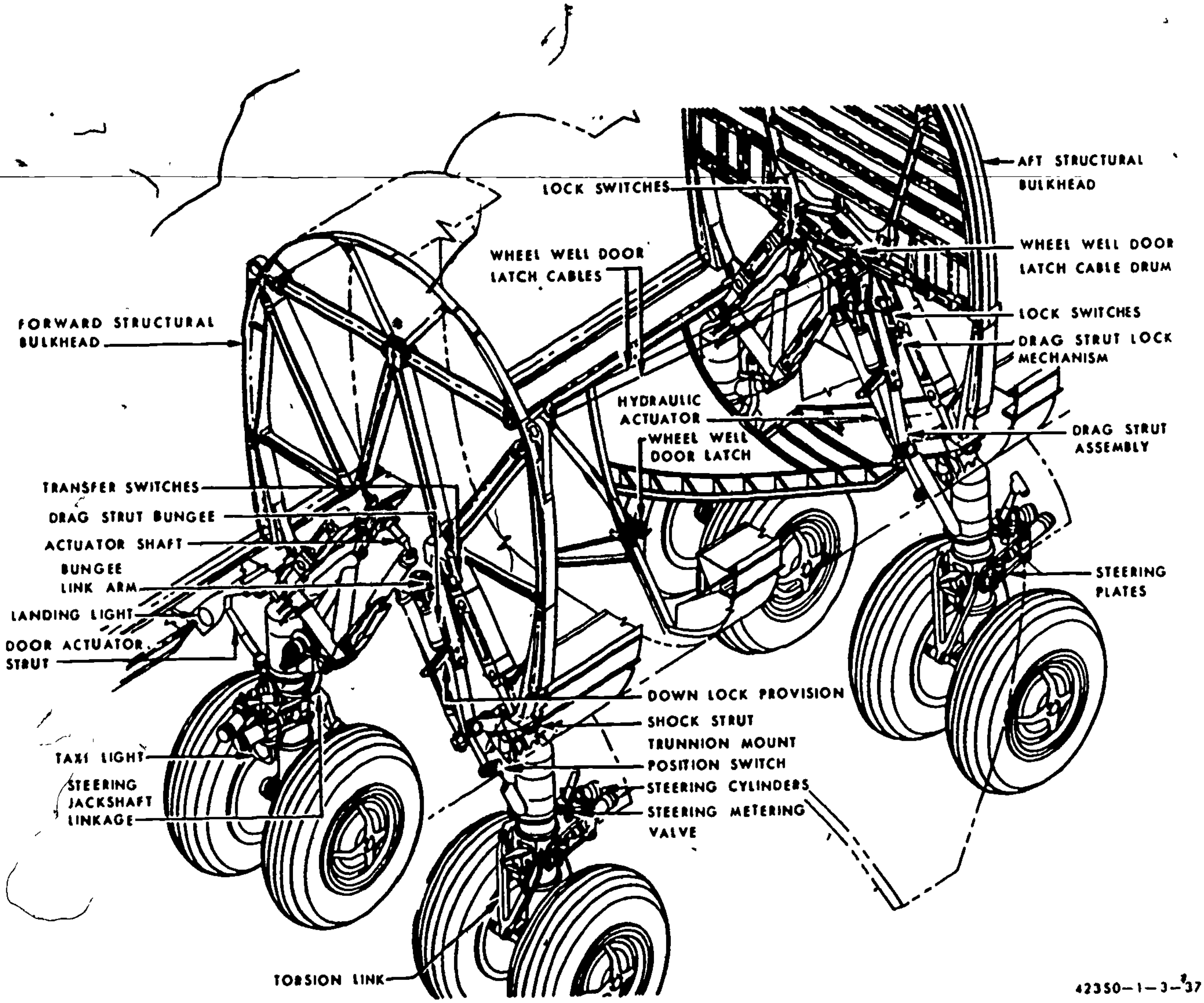

Figure 19. Landing gear system.

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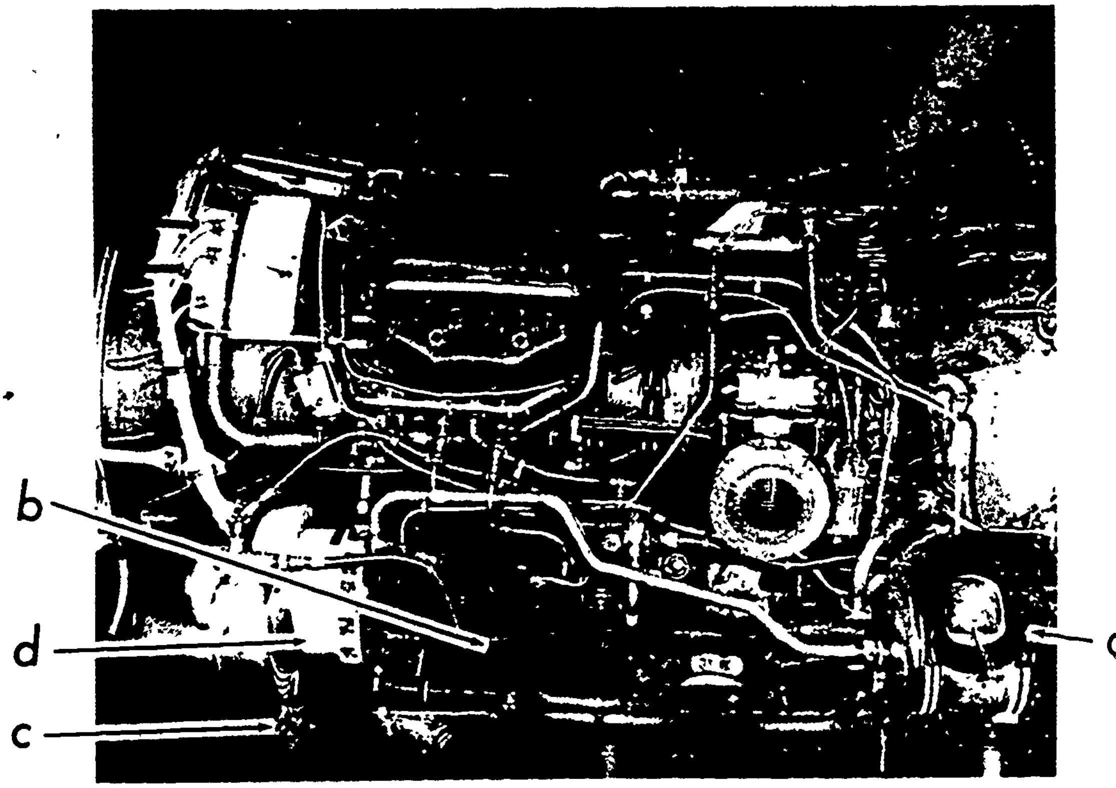

A. DRIVE OIL TANK
B. GENERATOR DRIVE UNIT
C. DRIVE OIL COOLER
D. GENERATOR

Figure 20. Typical generator drive unit.

7-2. **Hydraulic System.** Figure 17 illustrates an air-turbine-driven hydraulic system. There are 10 independent hydraulic pressure systems (power packs) located in the fuselage and wings, as shown in figure 17, to meet the hydraulic requirements. Each system has a low-pressure warning circuit that provides a visual indication of the normal pressure failure. This warning circuit is connected to a hydraulic pump pressure line of each system. In the event the turbine-driven pump is unable to maintain the normal operating pressure, there is an alternate source of hydraulic pressure. This alternate source is powered by a three-phase, motor-driven, AC pump which cuts in automatically when system pressure drops below a preset value.

7-3. Figure 18 shows an engine-driven hydraulic system. This system consists of six self-contained independent hydraulic power sections, and it functions in much the same manner as the turbine-driven system. Some of the features of the pack system were retained, but many were chopped.

7-4. The hydraulic low-pressure warning system was modified and retained. The automatic standby pump operation is not included in the engine-driven system. There are fire shutoff valves in the engine-driven hydraulic system. They are controlled by the engine fire shutoff switches. The shutoff valves control the flow of hydraulic oil from the hydraulic reservoirs to the engine pumps, thus permitting the oil flow to be shut off in the event of an engine fire. When an engine fire shutoff valve switch is pulled, the valve motor is energized. This causes the valve to close and interrupt the flow of hydraulic fluid.

7-5. Each of the individual hydraulic power systems has the function of supplying fluid under pressure to one or more hydraulically operated aircraft systems. Examples of the hydraulically operated systems are as follows: the landing gear, the wheel brakes, the steering, the cross-wind crab, the bomb doors, the inflight refueling, and the flight controls, as shown in figure 18. Here we will discuss only two of these systems, the landing gear and the brake system.

7-6. The particular type of landing gear that is shown in figure 19 is referred to as a quadricycle gear. The weight of the aircraft rests on four main gears positioned at the corners of a rectangle beneath the fuselage. Each of these main gears has dual wheels, providing eight tires that support the load of the aircraft. The main gears are electrically controlled, hydraulically operated, and mechanically locked.

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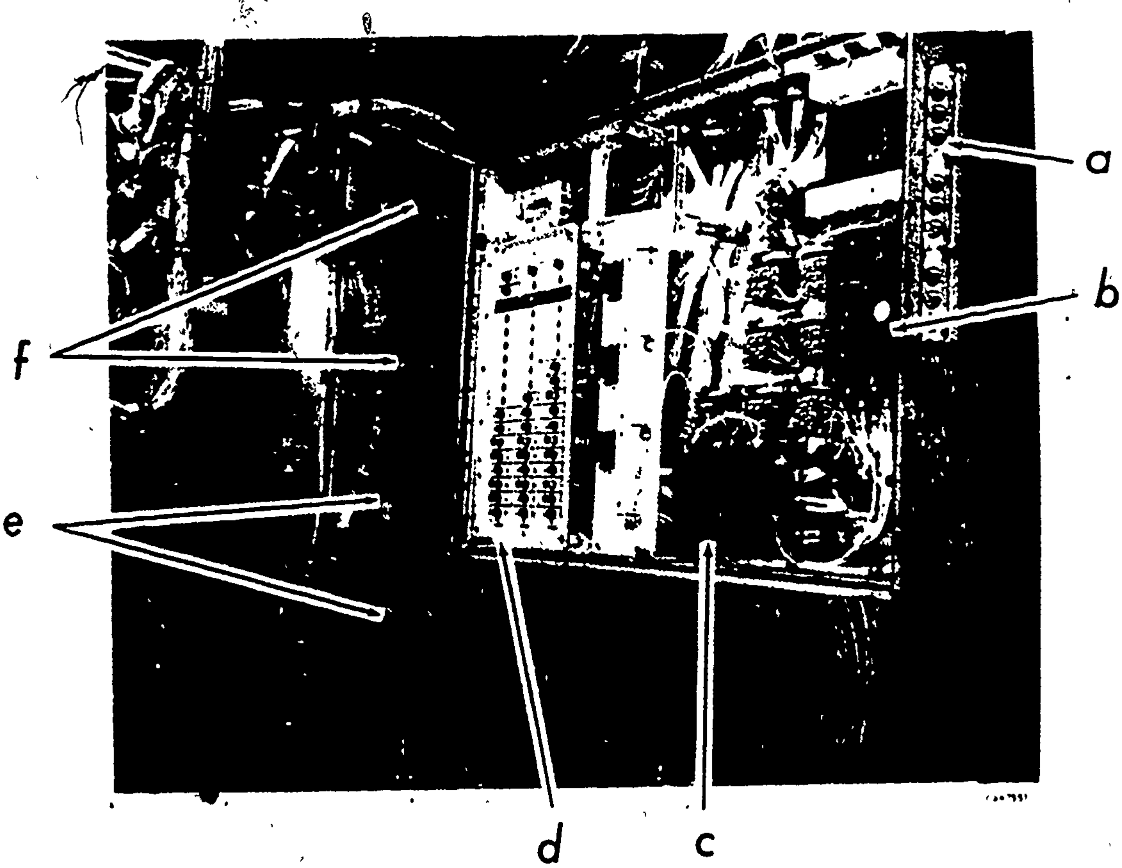

A. "POWER ON" LIGHTS
B. BUS TIE BREAKER
C. GENERATOR BREAKER
D. DISTRIBUTION CIRCUIT BREAKERS
E. VOLTAGE REGULATORS
F. GENERAOR CONTROL PANELS

Figure 21. Typical electrical installation.

7-7. On the quadricycle landing gear, the four main gears have expander tube brakes, and each wheel has an inner and outer brake assembly. The brakes are operated by applying toe pressure to either the pilot's or copilot's rudder pedals. To automatically prevent skidding of the tires during the landing roll of the aircraft, an antiskid system is installed. This system has individual skid detectors in the hubs of each main gear wheel and control relays, which in turn control solenoid valves in the brake lines. When a skid condition occurs or a wheel locks, a solenoid valve is actuated to release brake pressure on the skidding wheel. When it has recovered its rolling speed, the solenoid valves are released, and the hydraulic pressure is again applied to restore braking action. Another major system, as you know, is our own electrical system.

7-8. **Electrical System.** At the present, let us discuss, in general, the power systems you will study in greater detail in other volumes of this course. The electrical requirements on an aircraft are met by both AC and DC power supplies and distribution systems. For example, the alternating-current power may be furnished by AC generators; each driven by a pneumatic turbine or directly by the engine. The direct current may be furnished by TR (transformer rectifier) units which are powered from the AC power system. The 24-volt battery on the aircraft also provides DC when the main DC power is not available.

7-9. A typical generator drive unit is illustrated in figure 20. This unit (b) is mounted on the engine and drives the generator (d) at a constant speed. This unit is sometimes referred to as a CSD (constant-speed drive). The CSD output speed is regulated by a governor control system, and is powered from a gearbox in the engine accessory section. The drive unit is oil cooled, as illustrated in figure 20. The drive oil cooler (c) is supplied from the drive oil tank (a).

7-10. Each AC generator has a voltage regulator, as illustrated in figure 21. The voltage regulator (e) may be of a static type, transistorized printed circuit design. The regulator may be essentially a two-stage magnetic amplifier with multiple control circuits. If it is an exciter type regulator, then the unit takes AC power from the generator output, rectifies it, and sup-

Cartoon 5. AL—Gets a Blast.

plies this power to the shunt field of the exciter generator. This is required to maintain a constant voltage output. The functions performed by the regulator are voltage regulation, reactive load division, current limiting, and the rectification of the permanent magnet generator power output.

7-11. The AC system is also provided with generator control panels (f). The function of each panel is to protect the generator and generator drive in case the generator drive, voltage regulator, or frequency and load controller do not function to maintain system operation within the required limits. The generator breaker (c) and bus tie breaker (b), when closed, cause the power-on lights (a) to illuminate. The distribution circuit breakers (d) control power to individual circuits. You will study these components of the AC power system in other volumes in this course.

8. Servicing Materials for Aircraft Systems

8-1. Let's change gears now and discuss a related area. There is a variety of fuels, fluids, and lubricants used by the aircraft we have discussed. How these affect you and what you should know about them are the next points of discussion.

8-2. **Fuel, Fluids, and Lubricants.** It is not our intent to convert you to mature "grease monkey." However, you will be a much better electrician by having a general knowledge in this area.

8-3. *Fuel.* This is a liquid that has been refined or compounded to meet the requirements of a specific engine. It does a fine job of producing power when we use it in this manner. However, when people like Al use it for cleaning solvent or lighter fluid, they sometimes get an unexpected blast.

8-4. Fuel lines are color coded with a red marking tape. Don't connect any wiring to one of these. Most fuels will cause a skin rash or dryness and some cause lead poison. What am I saying? If at all possible, keep fuel off your skin. The fuel runs the engine, but what moves the flight controls and landing gear?—That's another good question; let's find an answer.

8-5. *Fluids and lubricants.* Hydraulic systems must be serviced with the proper fluid. Other systems need lubrication for proper operation. Hydraulic fluids are generally classified as to their type of base. For example, there is the petroleum-base fluid, the vegetable-base fluid, and the new synthetic-base fluid.

8-6. Petroleum-base fluid is presently being specified as MIL–H–5606. It is dyed red for easy identification and is supplied in 1-gallon containers, available in one grade only. This one grade has an operating range of −67° F. (−55° C.) to +160° F. (71° C.). The advantage of this wide operating range is the ability of the fluid to perform adequately in summer and winter temperatures. The seals required with the petroleum base fluid may be synthetic rubber, leather, or metal composition. This type of fluid is presently prescribed for use in most aircraft hydraulic systems.

8-7. Another petroleum base fluid is presently known as MIL–O–6083A. Fluid 6083A is intended for use as a preservative oil in shock struts, and as a flushing oil for some hydraulic components. It may also be used as an all-temperature operating fluid in independently serviced shock struts. However, it should not be used as an operating fluid in aircraft hydraulic systems.

8-8. Vegetable base fluid, Specification MIL–H–7644, is used in aircraft systems that use natural rubber seals. It has a bluish color and is easy to distinguish from the petroleum-base type. However, this vegetable-base fluid is becoming

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obsolete because it has to be supplied in two grades (A and C); grade A is heavy for summer use, and grade C is light for winter use. The use of the fluid is limited to hydraulic systems and units that have not yet been modified to use synthetic rubber seals.

8-9. The best way to determine what fluid must be used is to consult the maintenance instruction technical order applicable to that particular aircraft. Another method is to read the instruction plate affixed to the individual unit or reservoir and notice the color of the fluid contained in the system.

8-10. Whenever fluid is drained from an aircraft hydraulic system or component, it must not be reused. Instead, it must be tagged accordingly and disposed of as administratively condemned property according to applicable Air Force regulations.

8-11. Some of the hydraulic systems used in high-speed supersonic aircraft require specially developed hydraulic fluids that have an operating range of abnormally high temperatures. The main reasons for using this type of fluid are the close tolerance of the various actuating units, the specially designed metering valves, and the overall heat generated by the supersonic speed of the aircraft.

8-12. Synthetic base fluid, MIL-0-8446A, can be distinguished from other hydraulic fluids by its golden-amber color. Remember, MIL-0-8446A is not a general-purpose fluid. The maintenance instruction technical order should be

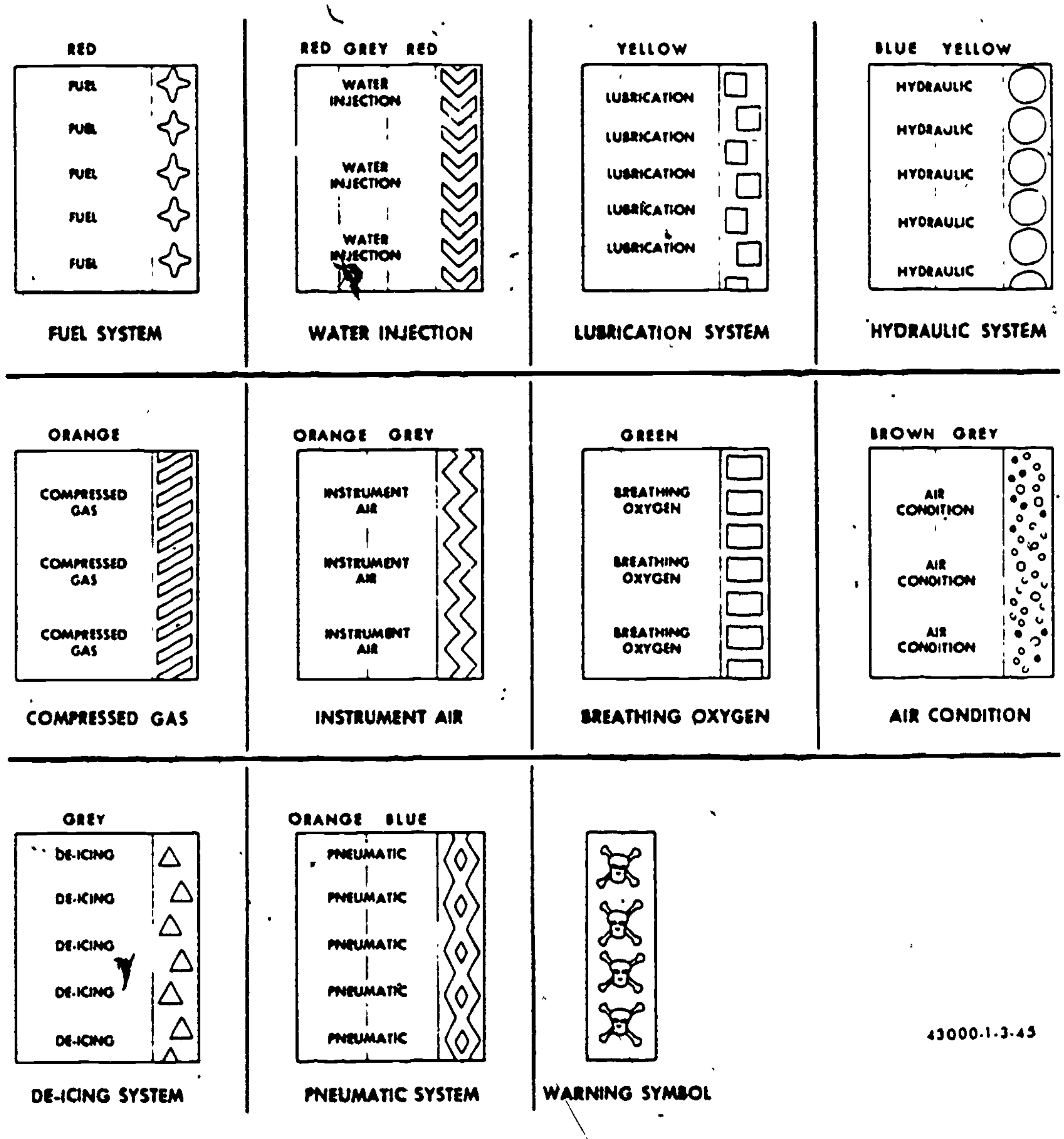

Figure 22. Typical color coding.

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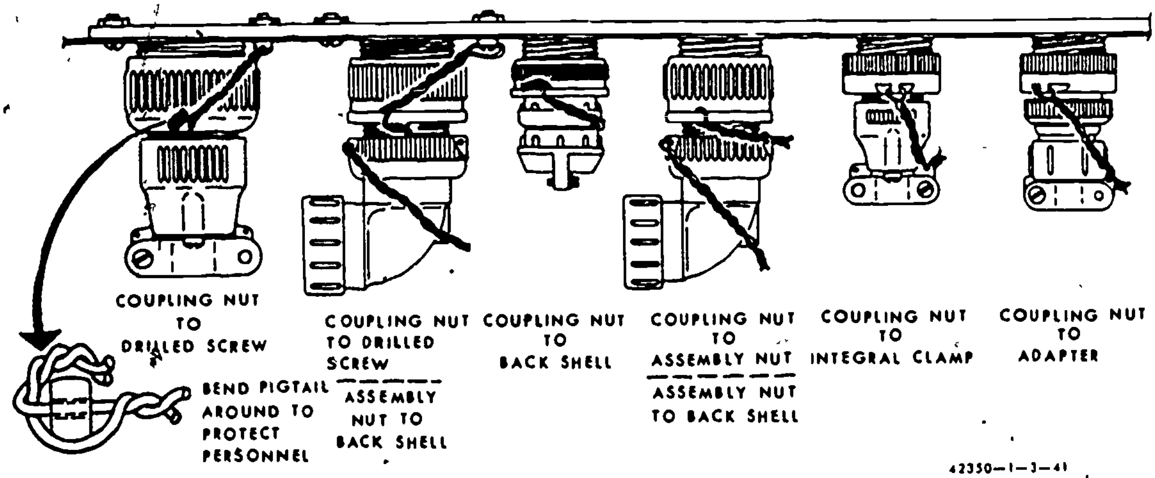

Figure 23. Safety wiring.

consulted before any servicing, flushing, or other maintenance procedures are carried out.

8-13. Seals used with MIL-O-8446A are not interchangeable with seals used with any other type of hydraulic fluid. Also, the seals used with MIL-O-8446A are hard to distinguish from other types of hydraulic seals. Hence, when replacing any seals used with the MIL-O-8446A, make certain that they are properly packaged and labeled when you receive them.

8-14. You will lubricate most units of an aircraft during the periodic inspection; using hand, brush, oil can, or pressure gun. You can find details for this lubrication in the servicing section of the aircraft maintenance manual and on the back of the inspection workcards. When using these lubrication charts, pay particular attention to the chart key and to the table of lubrication symbols. Greases are made to specification, according to operating temperature requirements. Always use the grease specified by the lubrication chart and follow the specific instructions listed on these cards.

8-15. Now that we have discussed these different fluids, fuel, and lubrication, how can we tell one system from another? This is easy to do from the filler cap end because it is labeled. What happens if you are in a wheel well facing a maze of tubing? There must be a coding system; agree?

8-16. **Color Coding on Plumbing.** We mentioned coding once when we were discussing fuels. Each system that uses plumbing or tubing as a means of interconnecting its components has a code.

8-17. Color codes on tubing are in the form of tapes or bands. A band is located on each tube segment, every 24 inches or less. In any event, a band is visible from any position. Figure 22 shows the common systems and their color codes.

8-18. The list shown in figure 22 covers most of the codes you will encounter. These will get you started. Remember, however, that in the maintenance instructions for an aircraft you will find the applicable color coding for that aircraft. Always refer to the technical order for a complete color-code listing.

9. Electrical Hardware and Handtools

9-1. We have discussed the aircraft in general, the types, how they fly, their major systems, and their service requirements. Now let's discuss some maintenance materials that you will use to keep the aircraft ready for flight.

9-2. **Electrical Hardware.** Just what do we mean by electrical hardware? These are the bench stock items that you, as an electrician, use to maintain the electrical system of any aircraft. However, the first item mentioned, safety devices, may be found in any bench stock.

9-3. *Safety devices.* Aircraft vibration tends to loosen or alter adjustment of various parts, such as nuts, turnbuckles, and screws. Therefore, parts that are intended for disassembly or adjustment are safetied by an auxiliary device or a "self-safety" feature. For example, the *cotter pin* is used for safetying various units such as castle nuts, clevis pins, and flathead pins. Cotter pins and safety wire are the most commonly used safety devices. Safety wire is used to safety screws, bolts, nuts, and electrical connectors. Figure 23 illustrates the safety wiring of electrical connectors. When replacing safety-wired electrical connectors, use only new safety wire; do not attempt to reuse the old safety wire. Be sure the safety wire does not become kinked or nicked

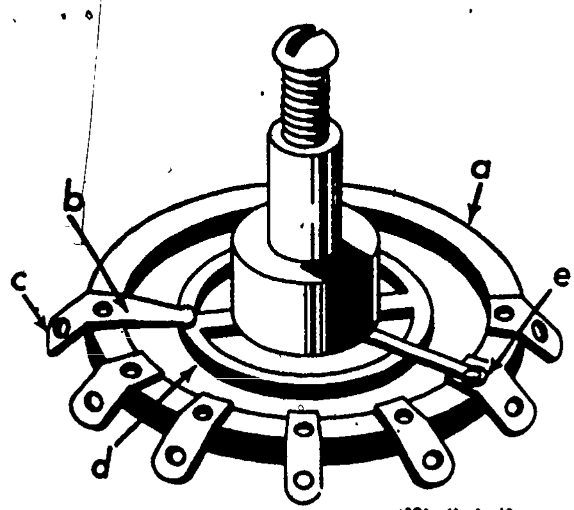

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Figure 24. Rotary selector switch.

during the twisting operation, and that the plating on the zinc-coated wire is not damaged. If wire is damaged, you should replace it with new safety wire. In order to align holes for safety wiring, you should not "back off" or overtorque the mounting fillister-head screws.

9-4. Copper wire, aluminum wire, or other similar wire called for in specific technical orders should be used as seals on equipment such as first-aid kits, portable fire extinguishers, emergency valves, or oxygen regulators. A secure seal indicates that the component has not been opened. When using safety wire as a seal, particular care should be exercised to assure that the safety wire will not prevent emergency operation of the devices. In all applications, the wire should be arranged between the parts or between a part and its anchorage in such a manner as to oppose any loosening of the part.

9-5. Another safety device is the *lockwasher;* it exerts spring pressure on the underside of a bolt or nut. Thus, the threads of the nut or bolt are kept under tension and resist any tendency for the bolt or nut to turn. It is recommended that you use a plain washer underneath a lockwasher to prevent the damage that may occur on soft metal surfaces. Also, plain washers should be used under nuts to provide a smooth-bearing surface. Now let's discuss some hardware that especially pertains to you as an electrician. The first of these is controlling devices.

9-6. *Circuit-controlling devices.* The proper functioning of electrical equipment depends upon its control-circuit operation. Directing current to a particular piece of equipment is not a complicated feat; starting, stopping, varying, and reversing the current is another matter. For these purposes, we must have other units if we are to control quickly and easily the various circuits found in aircraft. The most common control unit is the switch.

9-7. A switch may be described as a device used in an electrical circuit for making, breaking, or changing connections under conditions for which the switch is rated. Switches are rated in amperes and volts; the rating refers to the maximum voltage and current of the circuit in which the switch is to be used. Since it is placed in series, all the current will pass through the switch; because when it opens the circuit, the applied voltage will appear across the switch in the open circuit position. Switch contacts should be opened and closed quickly to minimize arcing; therefore, switches generally use a snap action.

9-8. Many types and classifications of switches have been developed. The common designation is by the number of poles, throws, and positions they have. The number of poles indicates the number of terminals at which current can enter the switch. The throw of a switch signifies the number of circuits each blade or contractor can complete through the switch. The number of positions indicates the number of places at which the operating device (toggle, plunger, etc.) will come to rest.

9-9. An example of the switch-position designation is a toggle switch that comes to rest at either of two positions, opening the circuit in one position and completing it in another. This is called a two-position switch. A toggle switch that is spring-loaded to the OFF position and that must be held in the ON position to complete the circuit is called a momentary contact two-position switch. A toggle switch that will come to rest at any of three positions is called a three-position switch.

9-10. Pushbutton switches have one or more stationary contacts and one or more movable contacts. The movable contacts are attached to the pushbutton by an insulator. The switch is usually spring-loaded and is of the momentary contact type. These switches have many uses; for example, they may be used as indicator light checks and for circuit reset. Occasionally you will find the push-on and push-off types of switches, but these types are not very common.

9-11. A rotary selector switch may perform the functions of a number of switches. This is accomplished, as shown in figure 24, by introducing power at the common terminal (c), which is mounted on the insulating ring (a). This power is then conducted from (c) through the stationary contact (b) to the conducting ring (d). Thus, power is available at the movable contact (e) at all times. As the knob of a rotary selector

switch is rotated, it opens one circuit and closes another. Some rotary switches have several layers of wafers. By adding wafers, the switch can be made to operate as a large number of switches. These switches are generally referred to as selector switches. Ignition switches and voltmeter selector switches are typical examples.

9-12. Mechanically operated switches are used for such purposes as landing-gear position indication, bomb-bay-door position indication, and as various drive limit switches. Many of these sensitive, snap-acting switches are found on aircraft. They are widely used because they are small, light, and very dependable. Although the term "Microswitch" is frequently used in referring to all switches of this type, it is a trade name for the switches made by the Microswitch Division of the Minneapolis Honeywell Regulator Company.

9-13. Switches of this type open or close a circuit with a very small movement of the tripping device ($\frac{1}{16}$ inch or less). They are usually of the pushbutton variety and usually depend upon one or more springs for their snap action. When the pressure of the plunger is removed, the spring again snaps the contact to the CLOSED position; this prepares the circuit for a new cycle. The versatility of this type of switch is tremendous because of the number of different mounting supports that have been devised for its support.

9-1.. A thermal switch usually incorporates a bimetallic strip that bends or snaps at a desired temperature to actuate the switch. This type of switch is found in fire and overheat warning circuits. The operation of these switches is automatic whenever the preset temperature is reached. They may either be used merely to turn on a light for an indication, or—in the case of an automatic control system—to start a chain of events for proper control.

9-15. While the switch itself is relatively simple to check, it sometimes presents a difficulty because it is located in an inaccessible place. After a visual inspection of the connections and the switch, a continuity test will indicate any malfunction. When the switch mechanism is found to be defective, it is usually replaced, since it is normally not reparable. Inclosed switches that are improperly sealed tend to allow moisture to condense in them, which shorts across the switch terminals and causes the switches to become defective. This difficulty may be corrected by carefully sealing the openings or using hermetically sealed switches. Hermetically sealed switches also prevent dust and dirt from reaching the contacts and thereby reduce the possibility of high resistance and open circuits.

9-16. Some switch assemblies are equipped with adjustments that enable them to operate at a preset time or pressure. These adjustments should be made carefully, since damage may result if they are not accurate.

9-17. The various types of switches we have discussed are used for the direct control of a circuit. But what about circuits that require heavy current flow or that simply cannot be regulated directly? For these, we have devices appropriately called relays.

9-18. Relays are electrically operated switches that are classified according to their use as control, power, or sensing relays. The use of relays saves space and weight in aircraft by permitting the use of small switches at remote stations. These switches permit the operator to control large amounts of current at other locations in the aircraft, and thereby the heavy power cables need only be run to the point of use. Only lightweight control wires are connected to the control switches. Safety is also an important factor in using relays, since high power circuits can be kept out of the cockpit.

9-19. The power relays are the workhorses of the aircraft's electrical system. As such, they control the heavy power circuits. The function of a control relay is to take a relatively small amount of electrical power and use it either to signal or to control a large amount of power. Control relays, as their name implies, are frequently used in the control of other relays, although the small control relays have many other uses. With these, electron plate currents can control the larger currents necessary to operate electrical devices. Control relays can also be used in so-called locknut, interlock, or sensing relay positions. The automatic functioning circuits in our modern aircraft could not function without the use of different combinations of relays.

9-20. A relay consists of a coil, a stationary iron core, and fixed and movable contacts. A small current is passed through the coil, creating a magnetic field. Then the core, by magnetic attraction, pulls down the armature to which the contacts are attached and completes the electrical circuit for the device which is to be operated. When the control circuit current is interrupted, the magnetic field about the coil collapses, and a spring forces the armature to return to its original position. This separates the contacts and opens the circuit of the device being controlled.

9-21. Many different types of relays are in general use today in various aircraft installations. The main differences between them are in operating voltages, current-carrying capacity, mounting, and control function (continuous or intermit-

tent operation). The data plate of the new relay should be checked before installation, because the outward appearance can be misleading. A relay designed for intermittent operation would not hold up very long if it were installed in a position calling for a continuous duty relay.

9-22. Variable resistance devices are used extensively in aircraft to control the intensity of lights and speed of various small motors. They also vary the voltage (and hence the current) to an operating unit within a definite range of values. Variable resistance devices are classed as either rheostats or potentiometers, depending on the number of electrical contacts they have.

9-3. A rheostat, sometimes referred to as a variable resistor, consists of a circular insulator around which a resistance material has been placed. A movable contact that contacts the resistance material is mounted on a rotatable shaft. The shaft is mounted concentrically with the insulating material. Circuit resistance is varied by the position of the movable contact. A knob is provided to facilitate adjusting rheostats which must be adjusted frequently. Rheostats that are designed for basic circuit calibration, rather than frequent adjustments, generally require a screwdriver for adjustment. In this case, the screw on the movable contact is loosened, and the contact is moved along the resistance strip until the desired resistance is obtained.

9-24. Rheostats are rated at normal temperatures in terms of maximum resistance, current, and power. This means that at normal temperatures the values stated are: the top resistance available in the circuit, the most current the rheostat can carry, and the most power that it can dissipate without overheating. All values must be taken into consideration when replacing a rheostat.

9-25. Another variable resistance device is the potentiometer. Most maintenance men refer to this device as a "pot." It is similar to the rheostat in external appearance. Potentiometers are rated in the same manner as rheostats; the ratings are resistance, current, and power. When they are used in circuits that require a variable resistance only, just one end connection and the movable contact are used. When a pot is used to adjust voltage (voltage divider), all three contacts are used. Input power may be applied across the resistance strip and output power taken from one end of the resistance strip and the movable contact. Power may be applied to the movable contact, and its position determines the magnitudes of the two voltages available at both ends of the resistance strip.

9-26. Electrical hardware has supplied the means of connecting and supporting the wiring which provides the path for electrical current throughout the aircraft. A means of overload protection for this wiring must also be provided. Therefore, we shall now discuss the various circuit-protection devices.

9-27. *Circuit-protection devices.* The electrical systems of an aircraft are protected from damage and failure by fuses, circuit breakers, and current limiters. The simplest overcurrent protection device is the fuse.

9-28. A fuse is a short length of wire or metal ribbon inside a suitably inclosed container. A current flow greater than the amount for which the fuse was designed causes the metal to heat and melt, opening the circuit which is being protected. A fuse is always placed in series with a circuit so that it opens the circuit automatically. The current capacity of each fuse is marked on its side. In the case of the cartridge type fuse, the current rating is marked on the ferrule (end cap). Also marked on this type fuse is an AG number (such as 3AG, 4AG) which indicates size and type body, in this case, a glass body. An AB number indicates a bakelite body.

9-29. Fuses are further classified as instantaneous or time delay types. The instantaneous fuse will carry its rated current indefinitely. but it will quickly open the circuit when it is rated capacity is exceeded by about 25 percent. Time delay or "slow blow" fuses (as they are generally called) are designed to stand overloads for some time before blowing. This feature is necessary to keep short-time surges, such as high-starting current for motors, from melting (blowing) the fuse. This time delay permits momentary high current without injuring the fuse, while continuous excessive current causes a rupture of the fuse.

9-30. Another consideration in the use of a fuse is the voltage rating. This rating refers to the maximum voltage possible in the circuit in which the fuse is used. It is the voltage that the fuse construction can safely handle without arcing. If the fuse opens, the entire applied voltage of the circuit will appear across it. Therefore, the voltage rating of the fuse should be higher than the maximum circuit voltage.

9-31. Fuses used in aircraft are not the reusable or reparable type. A fuse used in an aircraft must be replaced with a new fuse after the defective equipment has been repaired that caused the fuse to blow. When a fuse has a glass body, a simple visual inspection will reveal a blown fuse. With the bakelite—and sometimes even with the indicator type—fuses, it becomes necessary to use a multimeter and make a continuity check of the suspected fuse.

9-32. Current limiters are devices somewhat similar to fuses, and are used in aircraft circuits that carry heavy currents. This circuit protector consists of a copper link with a "weak section" of calibrated dimensions. These sections blow or melt in the same manner as those of the cartridge fuse when the circuit becomes overloaded or shorted. Two properly insulated and spaced bolts or studs are all that are required for mounting.

9-33. Current limiters are generally placed at both ends of a parallel bus feeder system. If a short occurs in the system, both current limiters will blow and completely isolate the fault. The remaining feeder leads can then continue to supply power to the bus.

9-34. When a high-current fault occurs in the main power distribution, all current limiters between the fault and the primary bus are subjected to an overload which may have affected their current-carrying capacity. Therefore, when such a fault is discovered, all limiters in the power circuit back to the primary bus should be replaced. If doubt exists about the magnitude of fault, limiters should be replaced, since damage to them may not always be visible. It is important to replace a current limiter with the proper type, since a time delay type does not provide the proper protection in a circuit that requires an instantaneous type.

9-35. The most commonly used circuit protection device in aircraft is the circuit breaker. It is designed to open the circuit under short-circuited or overloaded conditions without injury to itself. Thus, it performs the same function as the fuse or current limiter, but it has the advantage that it is capable of being reset and used again. In the same manner as the fuse, the circuit breaker is rated in amperes and voltage.

9-36. Circuit breakers used in aircraft are commonly categorized according to the way the circuit-breaking action is initiated; either thermal, magnetic, or thermomagnetic. Our coverage here is directed primarily to thermal circuit breakers, since they are the most widely used. Thermal circuit breakers are further divided into subcategories by the manner in which they are reset. These subcategories are push-to-reset breaker, switch breaker, or push-pull breaker.

9-37. A thermal push-to-reset type breaker uses a bimetallic strip to perform the breaking action. When the circuit is subjected to an excess of current, the increased heat causes unequal expansion of the two metals comprising the conducting strip, and the distortion bends the strip away from the electrical terminals. To reset the breaker, the operator merely pushes a button that forces the strip back onto the terminals. When this type of breaker is closed, the crewmember has no way of opening it.

9-38. Realizing that you sometimes find it necessary to open the circuit breakers manually, the manufacturers designed a type of thermal breaker known as the push-pull breaker. These breakers are equipped with a red collar that surrounds the operating shaft. When the circuit breaker is open, the red collar shows; when it is closed, the collar is inside the mechanism. This arrangement provides you with a quick way of visually checking any circuit-breaker panel for "popped" breaker. The push-pull circuit breakers are small, and their external projection from the panel is designed to reduce the possibility of catching your clothing on them and thus accidentally interrupting an operating circuit.

9-39. Another model of a thermal circuit breaker is called the switch type. The operator may open as well as close this kind of breaker. Externally, this breaker appears to be similar to a toggle switch. The togglelike mechanism is the resetter, which may also be used as a single-throw switch to turn the circuit on or off.

9-40. Circuit breakers are further classified as trip-free and non-trip-free. You can hold the non-trip-free circuit breakers closed while a tripping condition exists. This type of breaker is generally used in circuits that constitute an in-flight emergency if not energized, such as landing gear of flap circuits. These breakers should be held closed only in an emergency; and since this action is likely to change the calibration of the breaker, it should be replaced. The trip-free break is the more commonly used of the two types. This circuit breaker cannot be held in the reset position.

9-41. On the ground, whenever a circuit breaker interrupts the circuit, you check to determine the reason for the excessive current before any further attempt is made to operate the affected system. Sometimes circuit breakers become weak as a result of "old age" and of being tripped or reset so many times. These breakers should be replaced with new items. Along with controlling and protective devices, we must have a means of connecting wires together to make a complete circuit. This is the next point in our discussion.

9-42. *Terminals and splices.* Since aircraft wires are stranded, it is necessary for you to use terminal lugs to hold the strands together, which facilitates fastening the wires to terminal studs. The terminals used in electrical wiring are either of the soldered type or the crimped type. Terminals used in repair work must be of the size and type specified on the electrical wiring dia-

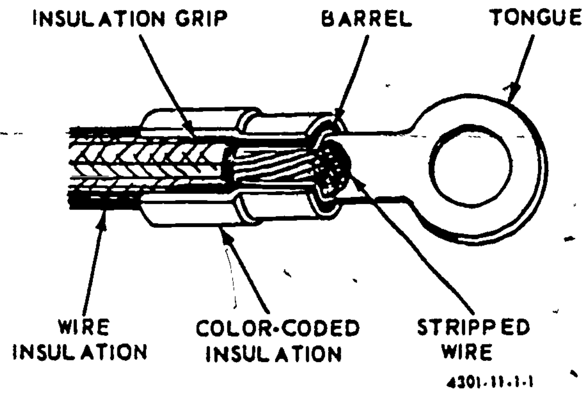

Figure 25. Preinsulated terminal lug (cutaway).

gram for the particular aircraft. In special cases, such as on thermocouple leads, the connections are soldered. Other than thermocouple connections, the soldering of splices and terminals is limited to emergency repair.

9-43. The increased use of crimp-on terminals is based to a large degree upon the limitations of soldered terminals. The quality of soldered connections depends mostly upon the technician's skill. Such factors as temperature, flux, cleanliness, oxides, and insulation damage caused by heat also contribute to defective connections.

9-44. The installation of the crimp-on solderless terminals requires relatively little technical skill. This allows terminals to be applied in an aircraft with a minimum of time and effort. The connections are made more rapidly, are cleaner, and are more uniform. Because of the pressures exerted and the materials used, the crimped connection or splice, when properly made, has an electrical resistance that is less than that of an equivalent length of wire.

9-45. Since both copper and aluminum wiring are used in current aircraft, both copper and aluminum terminals and splices are necessary. The copper terminals and splices should be used only on copper wire, and the aluminum terminals and splices should be used on aluminum wire. Various size terminal or stud holes will be found for each of the different wire sizes. A further refinement of the solderless terminals is the insulated type. The barrel of the terminal is inclosed in an insulation material (see fig. 25). The insulation is compressed along with the terminal barrel when crimping but is not damaged in the process. This eliminates the necessity of taping or tying an insulating sleeve over the joint.

9-46. You use different types of crimping tools with the different types of terminals and splices. Wherever possible, the manufacturer's crimping tool should be matched with his terminals and splices. Figure 26 shows some different brands and types of terminals and splices. Notice the different methods of crimping used on each. If you personally desire information about terminals and splices, refer to TO 1-1A-14. What if you need to make a connection that is not permanent? What kind of connection would you make? Let's continue and see.

9-47. *Electrical connectors*. Electrical connectors are designed to provide a detachable means of coupling between major components of electrical and electronic equipment. These connectors are constructed to withstand the extreme operating conditions imposed by airborne service. They must make and hold electrical contact without excessive voltage drop despite extreme vibration, rapid shifts in temperature, and great changes in altitude.

9-48. In the discussion which follows, we shall use the word "connector" in a general sense. It applies equally well to connectors designated by AN numbers and those designated by MS numbers. AN numbers were formerly used for all supply items cataloged jointly by the Army and Navy. Many items, especially those of older design, continue to carry the AN designation, even though the supply system is shifting over to MS (military standard) numbers.

9-49. Connectors consist of two portions—the fixed portion, called the receptacle, and the movable portion, called the plug. Plug assemblies may be of the straight type or the 90° type, while receptacle assemblies may be of the wall-mounting, box-mounting, or integral-mounting type. MS numbers and letters identify the type, style, and arrangement of a connector.

9-50. These connectors vary widely in design and application. Each connector consists of a plug assembly and a receptacle assembly. The two assemblies are coupled by means of a coupling nut, and each assembly consists of a metal shell containing an insulating insert which holds the current-carrying contacts. The shells of MS connectors are made in various types, each for a particular kind of application. A letter designation is used in the MS number to indicate the shell design or type. All MS connectors have aluminum alloy shells except Class K, which has a steel shell for fire resistance. Just be sure to replace a connector with an identical connector or an authorized replacement.

9-51. The present practice is to use potted connectors (moisture-proof or environment-proof connectors). However, operating conditions sometimes demand that ordinary electrical connectors on older types of aircraft be given a

moisture-proofing treatment. The basis of moisture-proofing is the application of a sealing compound to the back shell portion of the connector.

9-52. Moisture-proofing reduces failure of electrical connectors and reinforces the wires at the connectors against failure caused by vibration and lateral pressure; both of these conditions cause wire fatigue at the solder cup. The sealing compound also protects electric connectors from corrosion and contamination by excluding metallic particles, moisture, and aircraft liquids. As a result of its improved insulating characteristics, it reduces the possibility of arc-over between pins at the back of the electrical connectors.

9-53. TO 1-1A-14 gives directions for mixing and installing sealing compound. Prior to potting a connector, spare wires should be installed on all the unused pins. Use the largest gage wire that would normally be attached to each contact. The spare wires should be identified as to their size and pin connection. The exposed ends of these wires should be terminated with end caps.

9-54. The reason you solder a short length of wire to each spare pin is to provide for additional circuits to be included in the connector, or to reduce the need of repairing a single wire which may have failed within the connector by making a splice to one of the spare wires. If no spare wire is available in the connector and a single wire must be replaced, you take the back shell off and remove the potting compound with a knife or long-nose pliers. After you repair the wire, the plug may be returned to its original

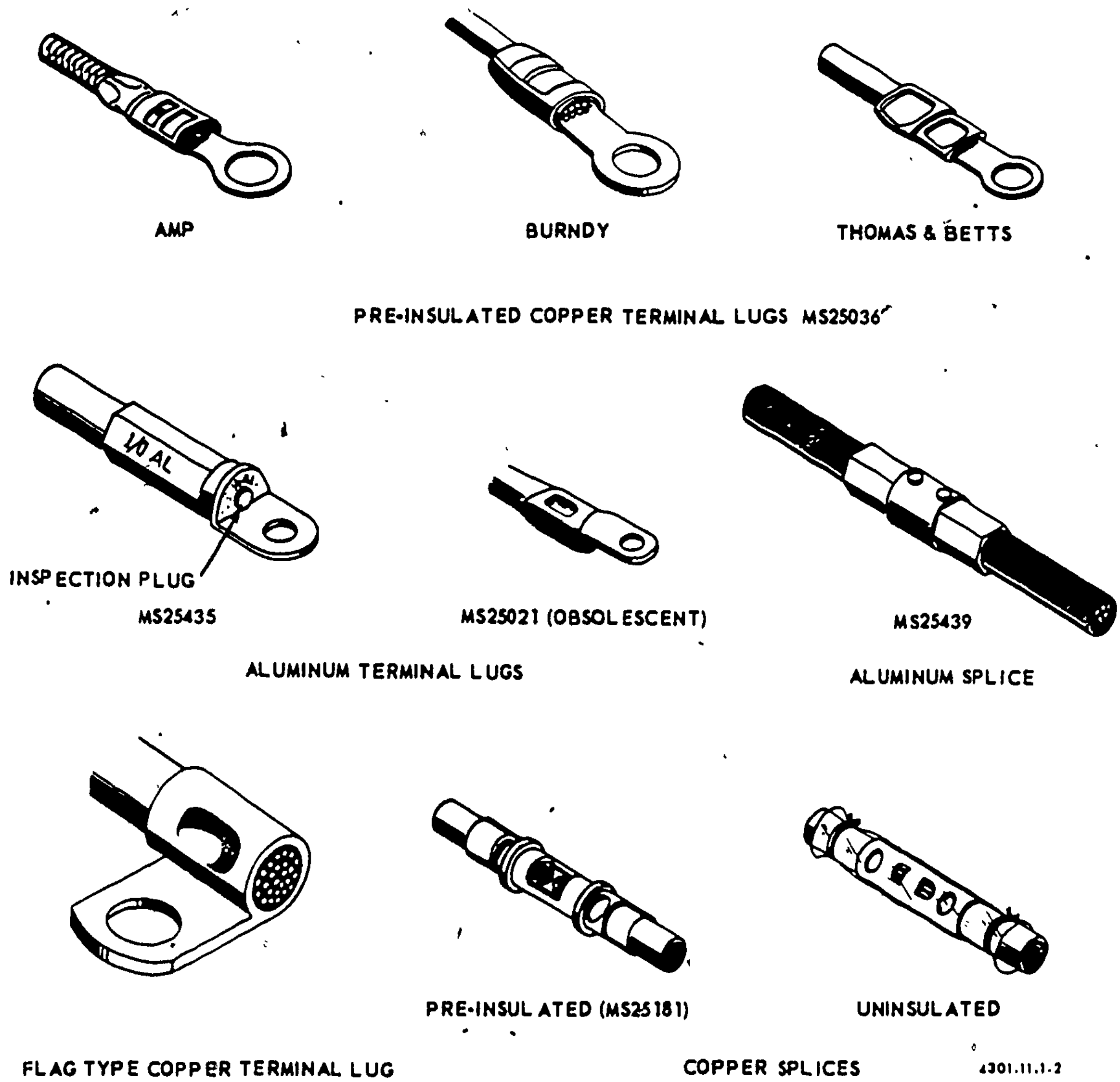

Figure 26. Solderless terminal lugs and splices.

condition by applying more potting compound. The new compound will seal or vulcanize satisfactorily to any old compound remaining in the connector. We have discussed different means of connecting or splicing wire, but we haven't discussed the wire itself. Let's turn our attention to electrical wire, as it pertains to aircraft.

9-55. *Electrical wires.* Materials used in the construction of wire are silver, copper, gold, and aluminum. Silver is a better electrical conductor than copper, but copper is more widely used for economic reasons. The fact that copper is used as a conducting material to a greater extent than any other material is accounted for not only by its ability to conduct electrical current and its relatively low cost, but also by its physical characteristics in general. It has high tensile strength, relative freedom from atmospheric corrosion, and is easy to solder.

9-56. Aluminum is the principal competitor of copper as an electrical conductor; you use it when minimum weight is a major consideration. In addition to its light weight, certain problems encountered with aluminum wire generally restrict its use to large-size wire and to positions such as power-feeder leads. Aluminum, however, has a number of disadvantages that must be considered when it is being installed in an aircraft. Aluminum wire, for instance, is softer than copper wire, and continued bending of aluminum wire will cause "work hardening" of the metal, which makes it brittle. This causes strands of the wire to fail or break much sooner than strands of copper wire. Aluminum wire with nicked strands should not be used on an aircraft because damaged strands will fail in service.

9-57. Another troublesome problem you encounter when using aluminum wire is the presence of electrically resistant aluminum oxide which you must either penetrate or remove to guarantee a satisfactory electrical connection. A compound called Penetrox A is used to remove this film.

9-58. For purposes of electrical and electronic installation in aircraft, an insulated wire consists of stranded aluminum or copper conductors covered with a dielectric or insulating material. This insulation may consist of several materials and layers. It provides dielectric insulation, thermal protection, abrasion resistance, moisture resistance, and fluid resistance. Insulated wire is usually referred to as "wire" and we shall refer to it in this way throughout this volume.

9-59. Wire size is designated by a wire gage numbering system. The sizes most commonly used on aircraft vary from number 22, the smallest, to number 0000 (sometimes written 4/0), the largest. This system closely approximates the American Wire Gage (AWG) system, but it is improper to refer to aircraft wire as AWG.

9-60. The approximate wire gage is determined by the smallest slot of the AWG wire gage that the stranded wire will pass through easily (each plot has an associated number). Slots larger than that associated with number 1 are identified by fractions which indicate the wire diameters. You use a wire gage for rough approximations in the field only when complete wire tables are not available.

9-61. Insulated wires are *rated* by the voltage the insulation can withstand and by the wire's current-carrying ability. You can obtain the information you need by referring to the military specification of a specific wire. For example, MIL-W-5086 is a simple conductor copper wire used for general-purpose wiring on most aircraft electrical systems. It is a stranded, tinned-copper conductor with insulation that is resistant to abrasion, moisture, and aircraft engine oils. It is also partly resistant to flame and fungus. Temperature limitations, ohmic values per thousand feet, and the current-carrying capacity are also given in the specification.

9-62. For wire replacement, you consult the aircraft's maintenance instructions manual first, since it usually lists the wire used in a given aircraft. When the wire size cannot be obtained from this manual, you select the correct size and type of wire needed. TO 1-1A-14 can assist you to make the proper decision while you consider the following factors:

- Current drawn by the load.
- Length of wire required.
- Allowable voltage drop of the wire.
- Maximum voltage applied.
- Approximate temperature to which the wire is to be subjected.

9-63. Wires built to withstand extremely high temperatures are used in certain installations. Take particular note of these installations to insure that general-purpose wiring is not used for replacement of high-temperature wire.

9-64. All aircraft wiring is identified by a numbering system. Therefore, new wiring to be installed in an aircraft must be properly marked before it is installed. Wires should be marked every 15 inches and 3 inches from each end. Wires less than 3 inches, or wires exposing both ends, need not be marked. Later in this chapter we will discuss the wire-marking machine. After marking the wire, it is properly cut, stripped, and tinned; and terminals or splices are installed.

9-65. Small copper wire may be cut to length with diagonal cutting pliers, but you cut large

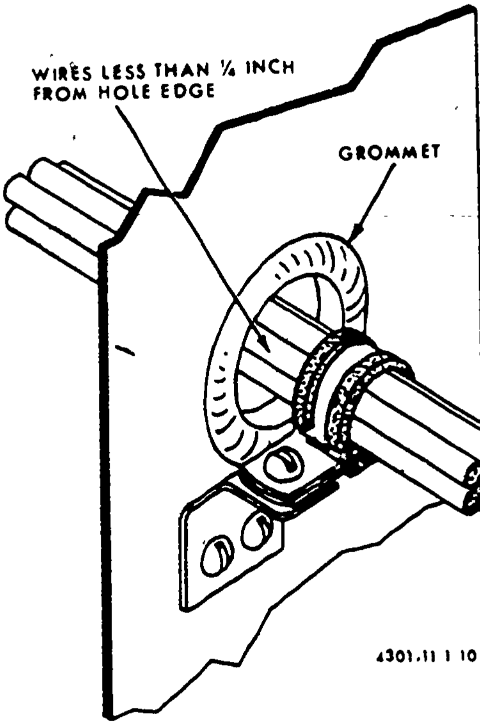

Figure 27. Cable clamp and grommet at bulkhead hole.

copper wire with a power circular saw which has a cable-cutting blade. A cable-cutting blade is similar to a meat-slicing blade that has no teeth. Copper wire may also be cut with a fine-toothed hacksaw.

9-66. Special cable shears with concave cutting edges may be used to cut small aluminum wire. Large aluminum wire should be cut with a power circular saw which has a cable-cutting blade. Aluminum wire should never be cut with tools that have reciprocating motion, such as hacksaws. Reciprocating cutting action "work hardens" aluminum wire.

9-67. Before wire can be assembled to connectors, terminals, splices. etc., you must strip the insulation from the connecting ends to expose the bare conductor. The amount of insulation you remove is determined by the connection that is to be made. Refer to TO 1-1A-14 for the proper length and for procedures. You strip copper wire in a number of different ways, depending upon size and insulation. The only authorized way to strip aluminum wire is with a knife. Even then, take extreme care not to nick the aluminum wire. Nicked or broken strands are not permitted on aluminum wire. On the other hand, the number of nicked or broken strands permitted on copper wire vary from 2 strands on number 10 wire to 12 strands on single 0 wire.

9-68. You install and route aircraft wiring in such a manner that it is protected from undue wear or chafing. Chafing and abrasion of electrical wires is generally eliminated if you use Military Standard (MS) cable clamps. Figure 27 shows the proper method of supporting a wire bundle that comes closer than one-fourth inch to the structure when passing through a bulkhead. If the clearance is greater than one-fourth inch, you need not use the grommet.

9-69. You also use MS cable clamps to provide a rigid separation (not for bundle support) when you route a wire bundle close to combustible fluid or oxygen lines. When this separation is less than 2 inches, inclose the wire bundle in a nylon sleeve for further protection.

9-70. Whenever possible, wire should be routed away from resistors, exhaust stacks, heating ducts, etc. If you must run wires through hot areas, the wire should be insulated with high-temperature-resistant material, such as asbestos or fiberglass. Never use low-temperature wire in these areas.

9-71. You never route wire below a battery. Wiring installed in a battery area should be inspected frequently, and any found to be discolored by the battery fumes should be replaced.

9-72. Avoid areas where the wires are subject to damage from fluids. If wiring might be soaked in any location, you inclose it in plastic tubing which extends beyond the wet area and is tied at each end. When wires and cables which are inclosed in tubing are depressed downward toward a connector, terminal block, etc., a trap or drip loop should be provided. The lowest point of the tubing should have a ⅛-inch drain hole, as shown in figure 28. This hole is punched

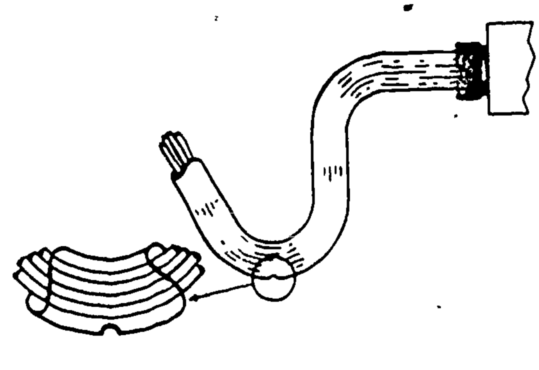

Figure 28. Drainage hole in low point of tubing.

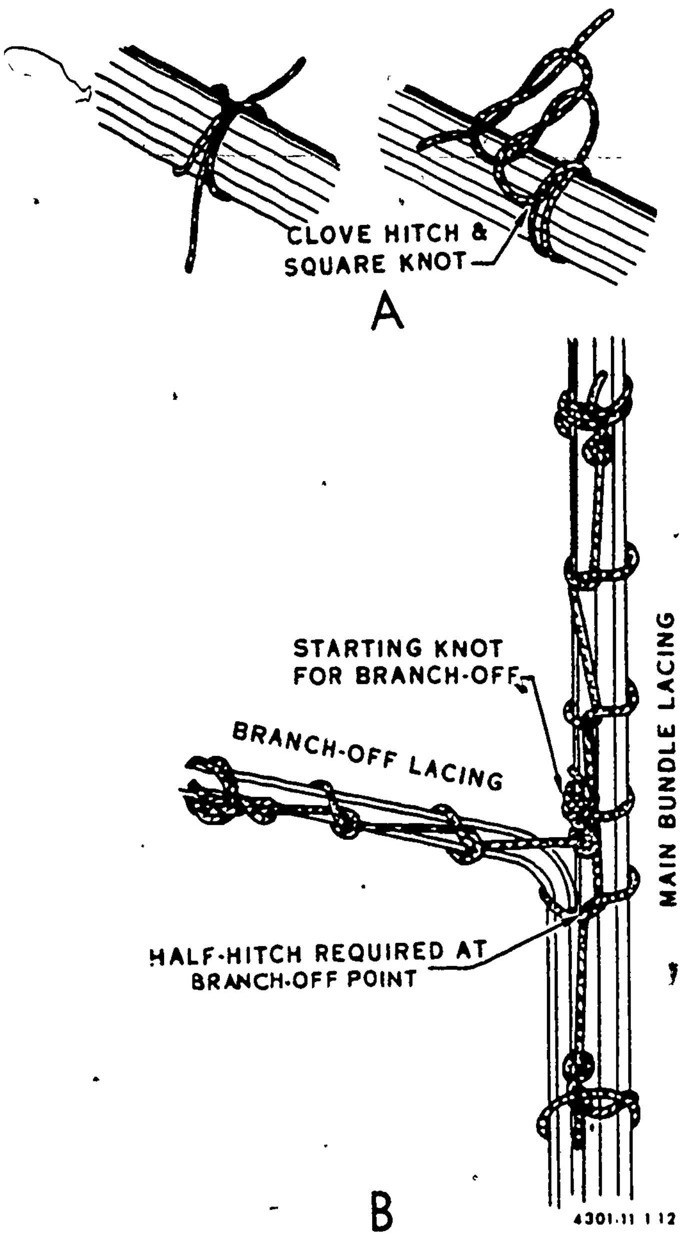

Figure 29. Wire bundle tying and lacing.

in the tubing after the installation is complete and the low point definitely established. However, the hole should not be punched in the tubing if the loop is in a wet area or is exposed to fumes detrimental to the insulation of wire.

9-73. You do not provide excess slack in wiring installation except for drip loop and service requirements. Enough slack should be provided to meet the following needs:

- Permit ease of maintenance.
- Allow replacement of terminals at least twice, where practicable.
- Prevent mechanical strain on the wires, cables, cable junctions, and cable supports.
- Permit free movement of shock- and vibration-mounted equipment.
- Permit shifting of equipment in order to make possible alinement, servicing, tuning, removing of dust covers, and changing of tubes, while installed in aircraft.
- Eliminate sharp bends in order to prevent breakage and damage to wire insulation.

9-74. Wires and cables that you attach to assemblies where movement occurs (such as hinges and rotating pieces, and particularly control sticks, control wheels and columns, and flight control surfaces) should be protected to prevent deterioration caused by movement of system components. This abrasive deterioration occurs when the wire or cable rubs together, or is twisted and bent excessively. As a design objective, bundles must be installed to twist instead of being bent across hinges.

9-75. Wiring that you install in wheel wells or other open areas that are subject to excessive wind and flying objects should be protected by flexible tubing or installed in metal conduit. The wiring installed in these areas (except in the metal conduit) should be inspected frequently for damage.

9-76. You lace or tie wire groups and bundles for ease of installation, maintenance, and inspection. By keeping all cables neatly secured in groups, the cable does not chafe against equipment or interfere with equipment operation.

9-77. Tying is the securing together of a group of bundle of wires by means of individual pieces of cord tied around the group or bundle at regular intervals (see fig. 29 part A). You make spot ties whenever the bundle supports are more than 12 inches apart. The ties should be spaced 12 inches or less apart. Lacing is the securing together of a group or bundle of wires inside inclosures by means of a continuous piece of cord forming loops at regular intervals around the group or bundle (see fig. 29, part B).

9-78. When lacing or tying, you observe the following precautions:

- Lace or tie bundles tight enough to prevent slipping, but not so tight that the cord cuts into or deforms the insulation.
- Do not place ties on that part of a wire group that is located inside a conduit.
- Lace wire groups in bundles only when they are inside inclosures, such as junction boxes. Use double cord on groups or bundles larger than 1 inch in diameter.

9-79. *Compact wire bundles.* Compact wire bundles are being installed in newer aircraft to

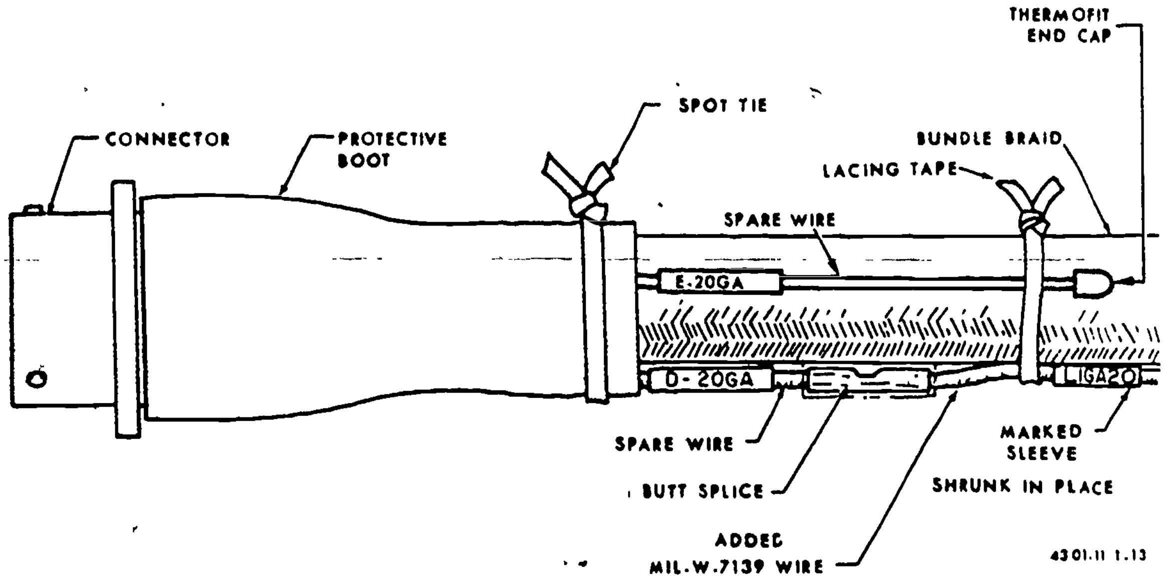

Figure 30. Protective boot on compact wire bundle.

save weight and space and to provide better protection with less maintenance. Compact wire bundles are fabricated from hookup wire. This wire has thinner wall insulation and is less abrasion resistant. Therefore, a braided outer jacket is required for abrasion protection. Solderless electrical connectors used on these harnesses are crimped, potted, and then covered with a protective boot. The boot extends back from the connector shell, covers the potting compound, and overlaps the braid to form a strong moisture-proof seal (see fig. 30).

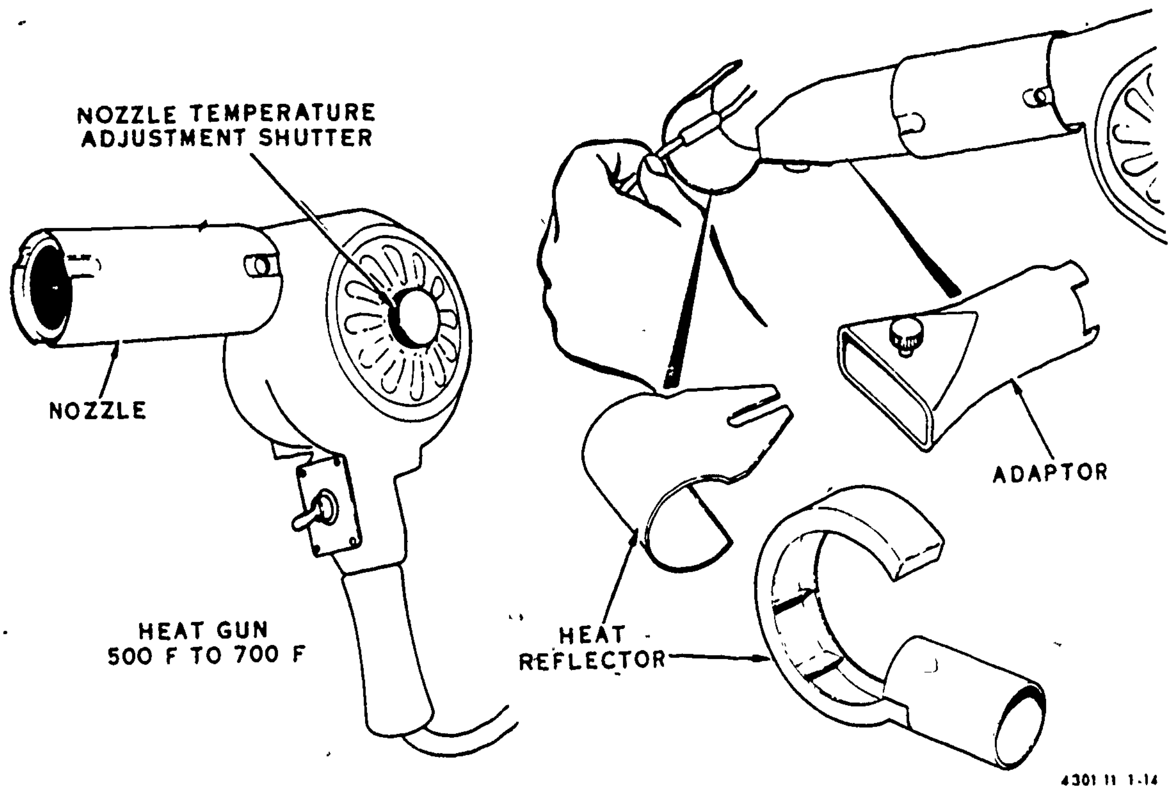

Figure 31. Heat-shrinking tools (for compact wire bundles).

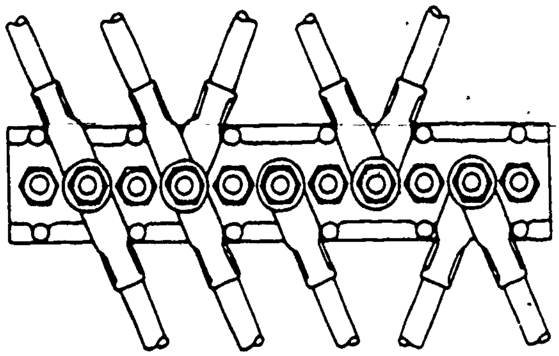

Figure 32. Connecting terminals to a terminal board.

9-80. Wires inside the bundle are spiraled in groups. Each group is composed of wires that leave the bundle at the same point. The wire group that extends the greatest distance should be placed nearest the center. Individual wires which branch out of the main bundle are covered separately with shrink sleeving. A wire number is stamped on this sleeve, and the sleeve extends into the braid covering. When spare wires are provided, they extend 4 to 6 inches from the end of the boot and are terminated in thermofit end caps, as shown in figure 30. These spare wires are secured to the bundle with lacing-tape ties.

9-81. The type of wire and the protection used for the fabrication of compact wire bundles have created situations that require special techniques for reworking the bundles. New crimping tools have been developed for installing special solderless connections. The thermofit materials are made from silicone rubber and require using new heating devices never before used in wire maintenance.

9-82. A special heat-shrinking process is used on the thermofit materials in the construction and repair of compact wire bundles. Thermofit is a material with special qualities which will shrink to at least half of its original diameter when heat is applied to it. Thermofit is used in the construction of boots, end caps, sleeving, and tubing.

9-83. Figure 31 shows the heat-shrinking tools used in the maintenance of compact wire bundles. The special adapters and reflectors make it possible to shrink most of the thermofit devices with the same gun. This heat gun must be used with extreme care because of its high operating temperature. One other component you, as an electrician, will encounter is the terminal block. Let's discuss it briefly.

9-84. *Terminal blocks.* Terminal blocks, sometimes referred to as terminal boards or strips, are made from an insulating material which supports and also insulates a series of terminals from each other as well as from ground. They provide a means of connecting terminals inside junction boxes and distribution panels.

9-85. Terminals should be installed on terminal boards so that any movement will tighten the nut. Figure 32 shows the different ways in which this may be done. Part A of figure 33 shows the proper method of stacking the required washers, and terminals, and securing nuts when connecting two copper terminals together on the same terminal board connection. Either a standard nonlocking nut or a self-locking nut may be used in conjunction with the lockwasher. However, the preferred method is to use an anchor nut, or self-locking nut.

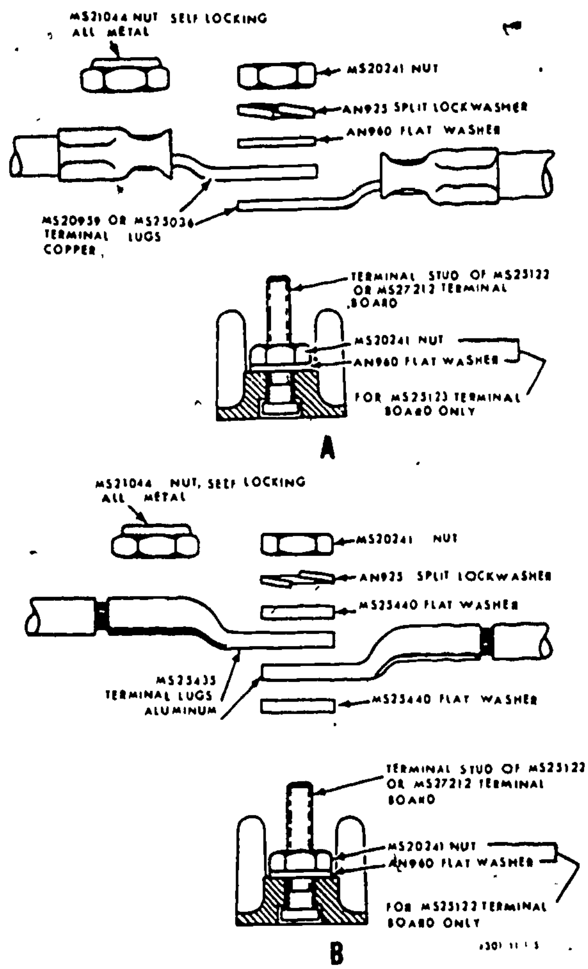

Figure 33. Hardware for wiring terminal boards (aluminum and copper terminals).

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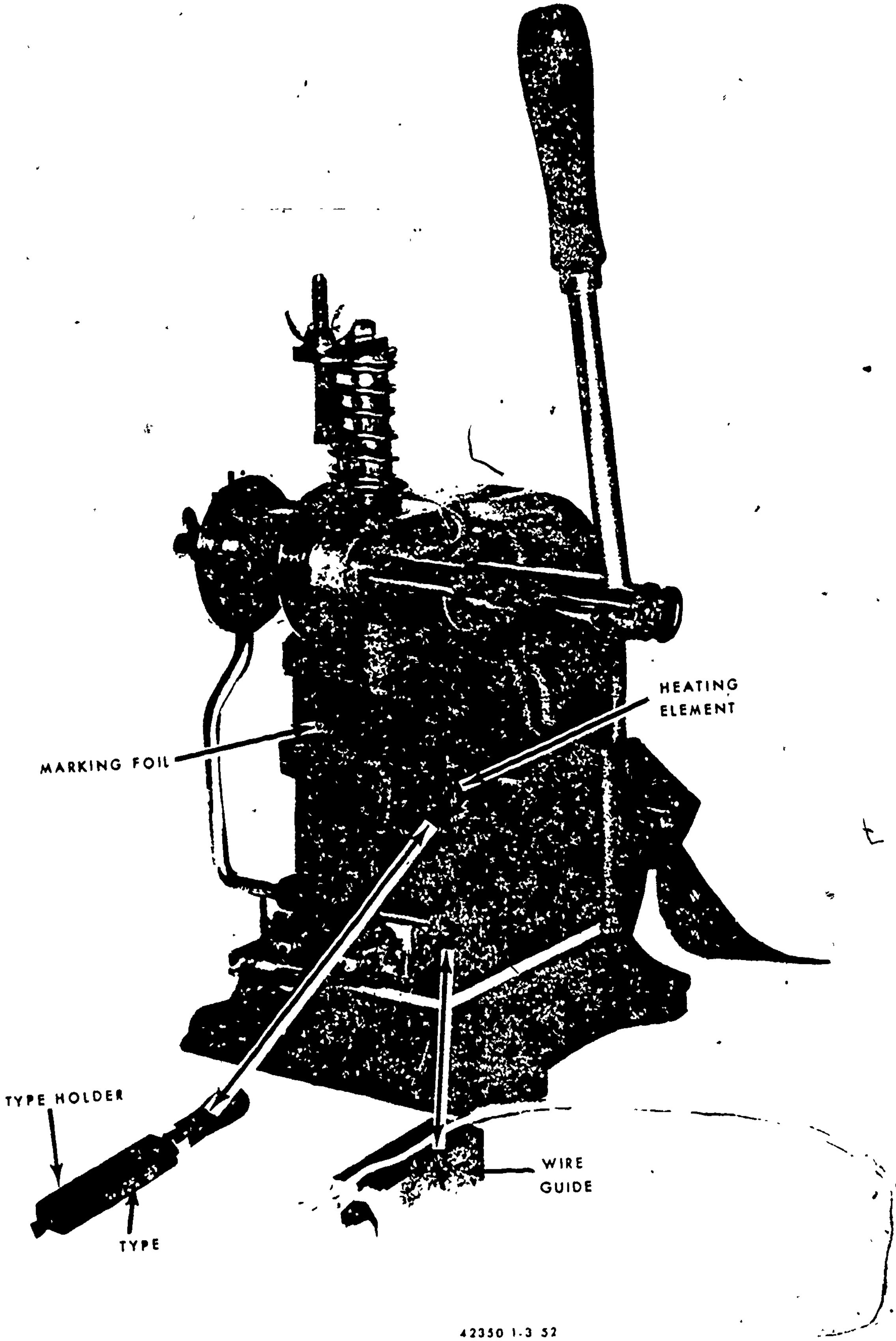

Figure 34. Wiremarking machine.

9-86. Part B of figure 33 shows you the proper method of connecting aluminum terminals together on a terminal board. Notice that in this method a washer is used between the bottom terminal and the terminal stud nut. The washers that make physical contact with aluminum terminals should be cadmium-plated. This prevents the dissimilar metals of the copper stud and the aluminum terminal from making contact. The dissimilar metals plus moisture will cause corrosion. This is known as the battery-effect form of corrosion.

9-87. Whenever it becomes necessary for you to join copper and aluminum terminals together on the same stud, they should be separated by a cadmium-plated washer. The aluminum terminal should be placed on the bottom with another cadmium-plated washer beneath it. A washer is never used between two aluminum terminals or two copper terminals. Placing a washer in this position only increases the resistance of the connection.

9-88. One final area of discussion concerning electrical hardware is bonding or grounding straps. These straps prevent the buildup of a static charge on the aircraft.

9-89. *Bonding and grounding.* A bond is any fixed union existing between two metallic objects that results in electrical conductivity between them. Such a union results from either physical contact between conductive surfaces of the objects or from the addition of a firm electrical connection between them. Aircraft electrical bonding is the process of obtaining the necessary electrical conductivity between the metallic parts of an aircraft. Aircraft grounding, a term closely associated with bonding, refers to the electrical connection made from a conducting object to the primary structure to provide a return path for current.

9-90. Clouds may become highly charged, as is evidenced by lightning. An aircraft in flight may also become highly charged. If the aircraft is improperly bonded, all metal parts will not have the same amount of charge. A difference of potential will then exist between various metal surfaces. The neutralization of the charges flowing in paths of variable resistance due to intermittent contact caused by vibration or the movement of the control surface will produce electrical disturbances (noise) in the radio receiver. If the resistance between isolated metal surfaces is great enough, charges can accumulate until the potential difference becomes high enough to cause a spark. This creates radio interference and constitutes a fire hazard. If lightning strikes the aircraft, a good conducting path is necessary for the heavy current in order to minimize severe arcs and sparks that would damage the aircraft and possibly its occupants. Bonding does the following things:

- Minimizes radio and radar interferences by equalizing static charges.
- Eliminates a fire hazard by preventing static charges from accumulating between two isolated members which could create a spark.
- Minimizes lightning damage to the aircraft and its occupants.
- Provides the proper "ground" for proper functioning of the aircraft radio.
- Provides a low-resistance return path for single-wire electrical systems.

9-91. Since we have discussed the hardware that will be common to you as an electrician, let us review the tools you will need to do your job.

9-92. **Electrical Handtools.** Tools of any kind are only as good as the individual using them. Naturally, tools wear out but this can be corrected. What am I getting at? Know each of your tools, what it was designed for, and most of all, how to use it. By doing this, you will have a head start on people like Al Lectric, who waits until he needs a tool before he learns to use it. Let's start with the wire-marking machine and then continue with some other tools that you will use.

9-93. *Wire-marking machine.* This is one tool that may sit on the shelf for 6 months before you need it, but when you do need it, there is no substitute. Figure 34 will give you an example of a typical hand-operated machine. This machine uses an electrical heating element which applies heat to the type holder and type. A roll of foil is positioned between the type and the wire to be marked. The wire is held in place by a wire guide, and a lever on the machine brings the type in contact with foil and wire. Pressure is then applied to the foil and it transfers marking material from the foil to the wire. The complete operating procedure is given in TO 1-1A-14. As an electrician, in addition to marking wire, you will also do quite a bit of soldering; so let's discuss the tools used for this operation.

9-94. *Soldering devices.* Generally speaking, you use either a soldering iron or a soldering gun. You may have a choice in many cases. Whichever you use, keep it clean and properly tinned. This is one of the secrets to good soldering.

9-95. If you are issued a soldering iron, you will probably be given several tips. These will

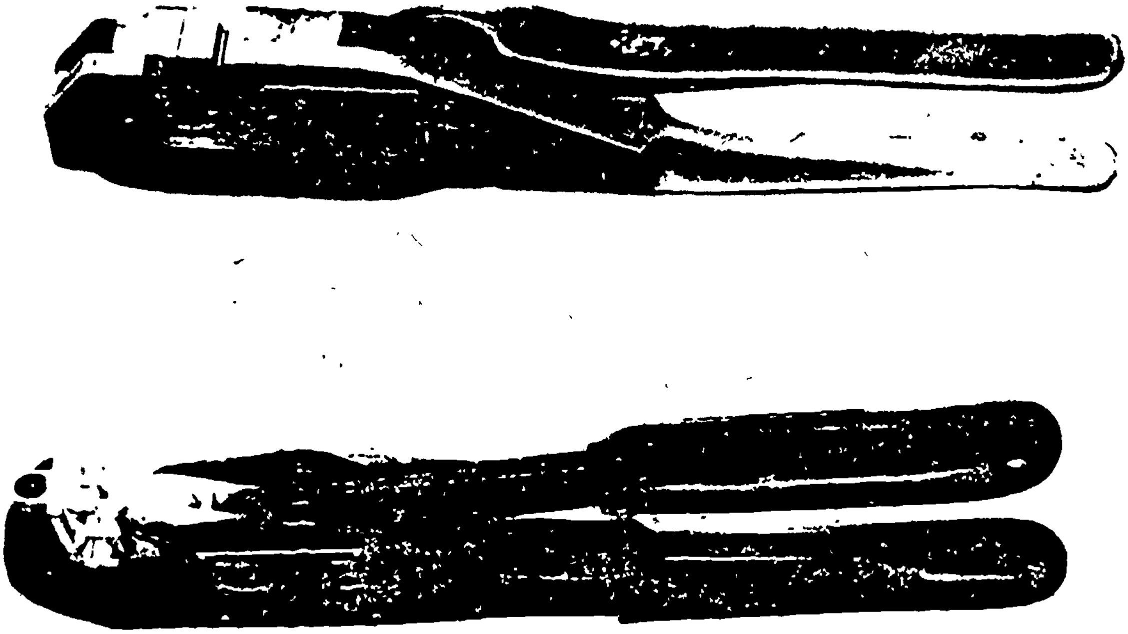

Figure 35. Crimpers.

come in assorted sizes and shapes. It will be up to you to use the correct tip for the job. When you solder a connector plug, use a tip that will give you sufficient heat without burning the insulation from adjacent wires. Again, keep it clean and tinned. *DO NOT* lay a *HOT IRON* where someone can burn himself.

9-96. Soldering guns come in a variety of shapes, but generally all of them have a tip for doing real fine or intricate work. Most of the soldering guns are controlled by a trigger. As long as the trigger is depressed the heating element will produce heat instantly.

9-97. Neither of these soldering devices will produce a quality solder joint every time unless you know what you are doing. What does this mean? It means each electrician (including you) must know how to solder. This is one of the most important jobs in maintaining electrical systems. You will save yourself many headaches by developing a good soldering technique, which comes through practice and experience.

9-98. The crimping tool has taken the place of the soldering iron in many places. This tool is easy to use and does not require any electrical power. Since you also use the crimping tool, discuss it at this time.

9-99. *Crimping tools.* Al uses water pump or diagonal pliers for his terminal crimping jobs. Naturally, you are the guy who has to replace Al's goofs so we need to discuss the right tool for crimping.

9-100. Figure 35 will give you an idea of the types of crimpers you may encounter. These tools make a flat type crimp, but some crimpers make an indent type crimp. The indent type crimping tool should be used only on the noninsulated terminals or splices. If this type crimping tool is used on a preinsulated terminal or splice, it will damage the insulation and cause a short or ground. For this reason they are being replaced.

9-101. The flat type crimping tool is used with the preinsulated terminals and splices. These crimpers will crimp a variety of terminal sizes. To choose the right one, check the color code or numerical coding on the tool. This color or numerical code determines the size of splice or terminal the tool will crimp. Before any of these terminals or splices can be crimped, the wire has to be stripped. To do this you need a wire stripper, which is the final tool we discuss.

9-102. *Wire stripper.* This device removes the insulation from an electrical wire. The one that you encounter on the flight line will be, in most cases, either a hand stripper or a common jack knife.

9-103. Figure 36 illustrates the strippers you use on the flight line. However, if you would like to see others look in TO 1-1A-14. The main thing to remember in using a wire stripper is not to damage the wire strands. A good look at figure 37 and a few hours of experience will make you proficient in the task of stripping wire.

9-104. The electrical handtools we have discussed are not your complete issue of tools. You have others and you need to know what each one does. If you keep them clean and use them for the job for which they were designed, they will make your job easier.

9-105. The tool we use to keep aircraft clean and in operational status is an aircraft inspection system. Let's turn our attention to the inspection requirements of the electrical system.

10. Aircraft Electrical System Inspections

10-1. Why do we have to inspect the electrical system? Why not wait until a problem exists before looking for one? You have probably heard these questions before, or maybe you have asked them. You have probably heard this remark also, "I never find anything wrong, so why worry about it." This sounds like Al Lectric talking. People of this caliber generally think this way. I'm sure this doesn't include you; you are the professional.

10-2. **Purpose of Inspections.** Aircraft inspections are designed to prevent aircraft disablement and flight schedule interruption. It is much easier to locate and fix a discrepancy when the aircraft is in for inspection than to wait until it is loaded and ready for flight.

10-3. As an aircraft electrician, you are required to inspect aircraft electrical systems. Do you know what you are supposed to look for when you perform an inspection? Obviously, no inspection can be a random, hit-or-miss affair; each must be conducted in an orderly sequence so that every important item is inspected.

10-4. Inspections of electrical systems are covered in great detail in Technical Order 8-1-1, *Aircraft Electrical System Inspection Procedures.* You should become familiar with the contents of this technical order because it tells you the conditions that *should* exist in all electrical systems, as well as those that *should not* exist. The items of inspection that pertain only to an electrical system for a particular aircraft are listed in the inspection workcards for that aircraft. For now, let's discuss the conditions that should exist in *all* electrical systems.

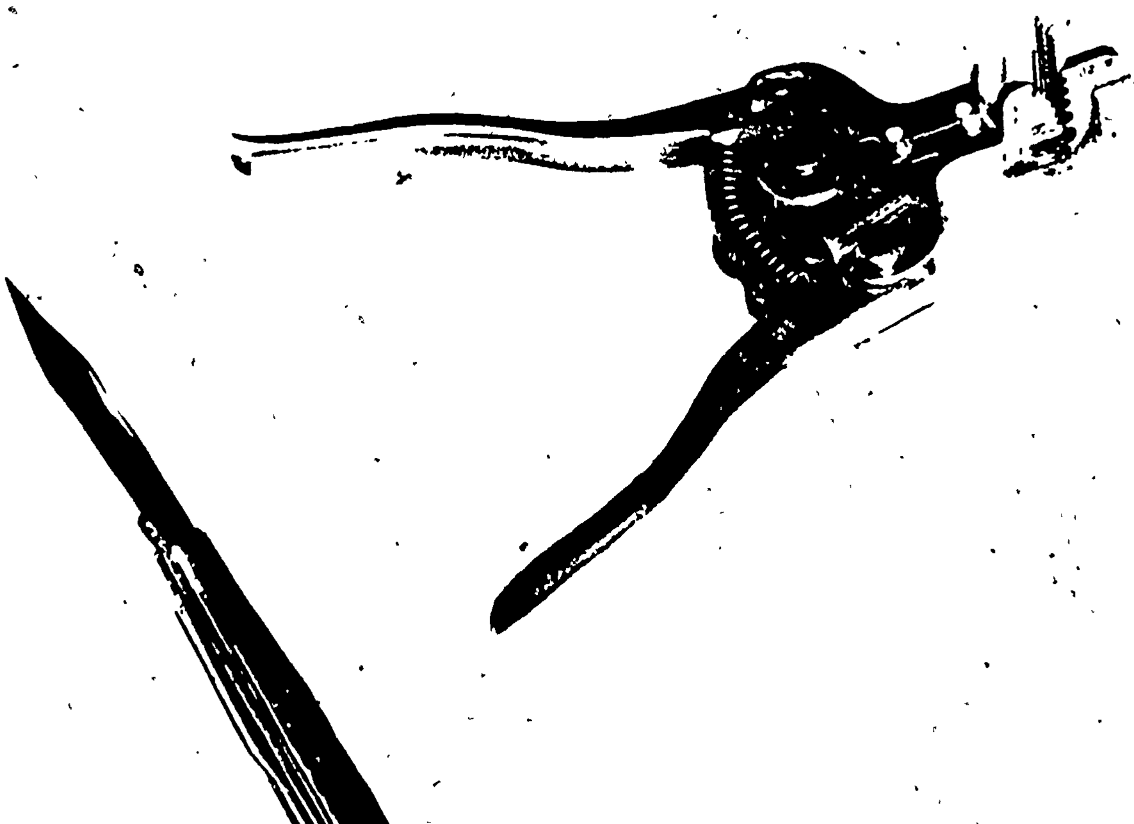

Figure 36. Strippers.

10-5. **Inspection Data.** All aircraft electrical wiring must be installed so that it is mechanically and electrically sound and neat in appearance. You should protect wires and wire groups from the following:

- Chafing or abrasion.
- High temperature.
- Possible use as a handhold, or as support for equipment or personal belongings.
- Damage from cargo being stored or shifted.
- Damage from personnel moving about within the aircraft.
- Damage from battery acid or fumes.
- Damage from volatile fluids or solvents.
- Abrasion in the wheel well areas.

10-6. As far as possible, you should keep wires separate from high-temperature equipment, such as resistors, heating ducts, and exhaust pipes. When it is necessary for you to route wires through hot areas, they must be insulated with fiberglass, abestos, or teflon. In some cases, conduit may be specified. In these cases, use conduit with high-temperature liners, or use high-temperature plastic tubing.

10-7. You must protect wire and wire groups against chafing or abrasion where contact with sharp surfaces or other wires might damage the insulation. Damaged insulation may result in shorted circuits, malfunction, or inadvertent operation of the equipment. When wires pass through a bulkhead, they must be installed with a clamp. If the wires come closer than one-fourth inch to the hole, you should use a suitable grommet to protect the wire insulation. If it is necessary to cut the grommet to facilitate installation, cut through the grommet at a 45° angle. Wires or wire bundles should be installed so that they are protected by the aircraft structure. Conduit should be used to prevent cargo from pinching the wires against the airframe. Bundles should be placed so that personnel are not tempted to use them as handholds or ladder rungs.

10-8. You should not route wires under a battery. Wires installed in the vicinity of a battery should be inspected frequently. Any wires that are discolored by battery fumes should be replaced.

10-9. Avoid routing wires in areas where they might be damaged by fluids. Wires should never be routed in the lowest 6 inches (bilge) of the aircraft, or in any other area where spilled liquids might collect. If there is a possibility that a wire without a nylon jacket might be exposed to fluids, it should be covered with plastic tubing for protection. If you use plastic tubing to protect wiring, the tubing should extend beyond the possible wet area to each end and be securely tied. The lowest point of tubing in dry areas should have a ⅛-inch drain hole.

10-10. Wires that are located in wheel wells or wing-fold areas are subject to many additional hazards, such as pinching, flexing, and exposure to fluids. You should cover all wires in such areas with flexible plastic tubing tied securely at each end. There should be no relative movement at points where the flexible tubing is secured. The wiring located in these particular areas should be inspected frequently in accordance with applicable directives and replaced or repaired at the first sign of wear. There should be no strain on the wire assemblies when the parts are fully extended, but the slack should not be excessive.

10-11. You must always route electrical wiring parallel to combustible fluid or oxygen lines and separate it from the lines by at least 6 inches. The wires should be routed on a level with, or above, the plumbing lines. The wires should be clamped in such a manner that if a wire breaks at a clamp it will not come in contact with the plumbing line. When the wires must be routed closer than 6 inches from the plumbing lines, clamp both the plumbing line and the wire bundle to the same structure to prevent relative motion. It may be necessary to use a nylon sleeve over the wire bundle to give further protection. Use two cable clamps to maintain separation. The clamps are used for separation only—not for supporting the bundle. Under no circumstances should wires be routed within ½ inch of a plumbing line. Plumbing lines carrying flammable liquids or oxygen should not be used to support wire or wire bundles.

10-12. Wiring should be routed to maintain a minimum clearance of 3 inches from all control cables. If you cannot maintain this clearance, install mechanical guards to prevent the wire from coming into contact with the control cables.

10-13. Wire and wire bundles should be supported by clamps or grommets at intervals of not more than 24 inches. The approved clamp for Air Force use is type MS21919, which is cushioned with insulating material. You should never use clamps without cushioning material to support wire. A type AN735 clamp should be used to clamp wire to a tubular structure.

10-14. Wire bundles should be rotated so that they are parallel to the rib structure of the aircraft or at right angles to the rib structure. Avoid routing the wire bundle at an angle to the aircraft rib structure. Wires or wire bundles should be installed so that the slack between clamps should not exceed one-half inch with normal hand pressure. The slack must never be so great that the

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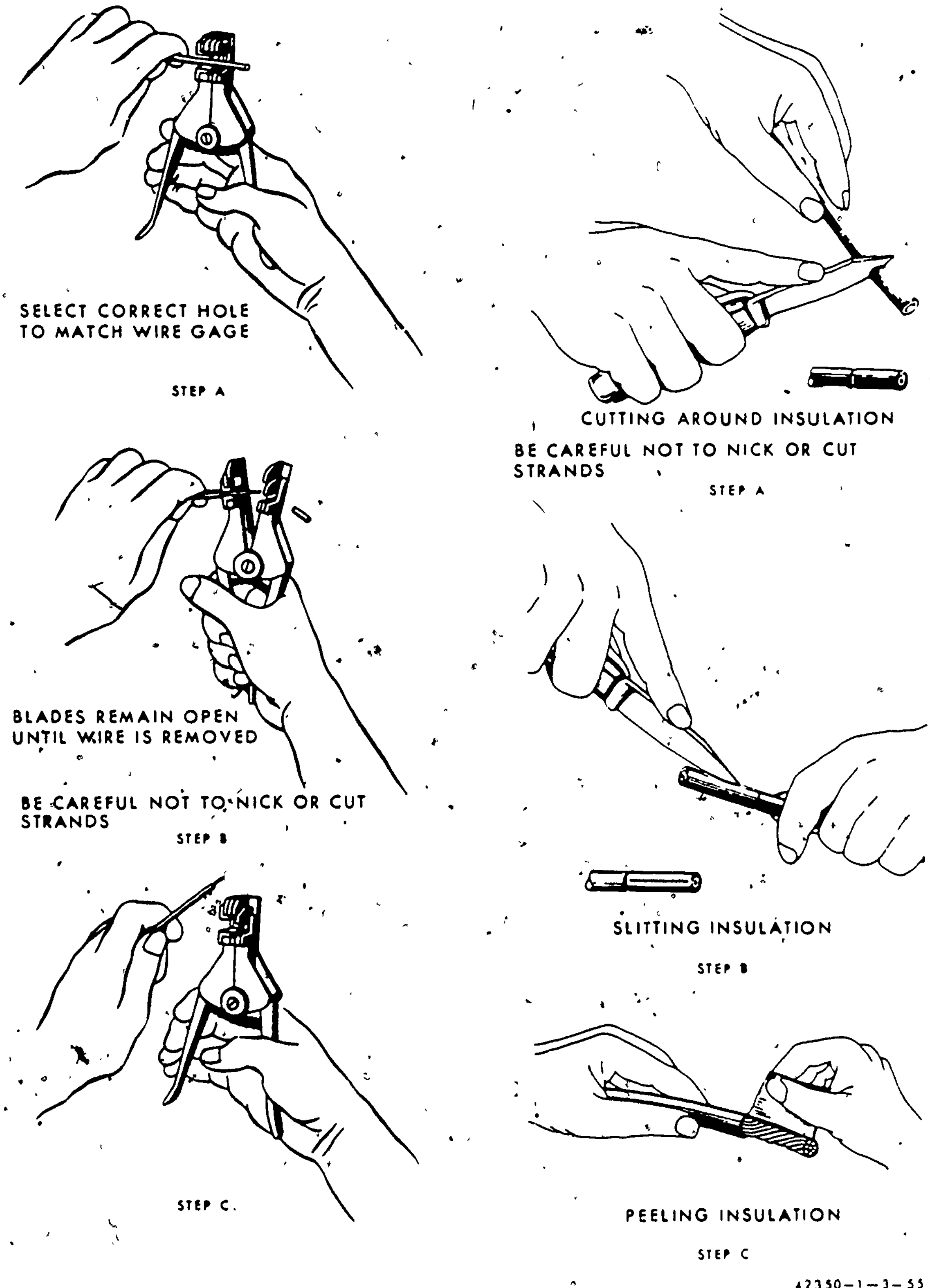

Figure 37. Use of wire strippers.

wire or wire bundle can come in contact with a surface that might cause abrasion. However, remember as we mentioned previously, there must be sufficient slack to do the following:

- Permit easy maintenance.
- Allow replacements of terminals at least two times.
- Prevent mechanical strain.
- Permit free movement of shock-mounted equipment.
- Permit shifting of equipment for maintenance purposes.

10-15. Wire bundles inside junction boxes must be supported by cushioned cable clamps across hinged doors. The correct method is to twist the wires across the hinge when the door is opened. The incorrect method causes the wires to bend when the door is opened and damages the wire or insulation.

10-16. Wire bundles should be attached to the walls of junction boxes in such a manner that there is no chafing against the terminal studs or other components in the box. Any slack that is required for terminal rework must be tied to prevent snagging.

CHAPTER 4

Portable Test Equipment for the Electrician

IN THE FIELD of electricity, as in all other physical sciences, accurate quantitative measurements are essential. This involves two important items, numbers and units. The numbers are simple arithmetic in most cases, and the units are well defined and easily understood. Standard units of current, voltage, and resistance, as well as many other units of measurement, have been defined earlier in this volume.

2. As an electrician, you will work with ammeters, voltmeters, and ohmmeters, as well as special test equipment that will be covered as we progress through this course. It is important that you have a good understanding of the function, design, and operation of electrical instruments. In your work you use the following equipment to determine if the circuits of a system or a system component are operating properly:

- An ammeter to measure the amount of current flowing in a circuit.
- A voltmeter to determine the voltage existing between two points in a circuit.
- An ohmmeter or a megger (megohmmeter) to measure circuit continuity and total or partial circuit resistance.

3. You may also find it necessary to determine the total power being consumed by certain equipment; in which case, you will have to use a wattmeter. For measuring other quantities, such as power factor and frequency, you will need to use still other types of electrical instruments.

4. In each case the instrument indicates the value of the quantity measured, and you interpret this information to understand the way the system or component is operating.

5. Let us point out again, that as an electrician, you need a thorough understanding of the operation and limitations of various types of electrical measuring equipment coupled with the theory of circuit operation. This is most essential in troubleshooting, servicing, and maintaining electrical systems and equipment. Before we can discuss different types of meters, we must first review the basic meter movements, the first of which will be the D'Arsonval.

11. Meters

11-1. Most of the electrical quantities can be measured by meters that indicate the value in terms of a specific unit on a calibrated scale. Different types of construction are used in the manufacture of meters, largely because of their various uses. Regardless of use, the heart of an electrical meter is the meter movement.

11-2. **D'Arsonval Meter Movement.** The electrical energy that is applied to the movement is changed into mechanical energy. This results in needle movement across a calibrated scale to provide a visual indication of the amount of the electrical element being measured. Of the many types of meter movements that have been designed and used, the moving-coil movement is the most important. You find this movement in most of your test instruments, and it will be discussed here.

11-3. The reaction between a stationary magnetic field and the magnetic field around a DC coil provides the turning force for moving the coil in the moving-coil type meter. The current in the coil creates a magnetic force field which reacts with the stationary magnetic field in which the coil is placed. This reaction results in rotation of the coil. To produce a useful interaction, the current flow in the coil must always be in the same direction and of the proper polarity. Therefore, the moving-coil meter (D'Arsonval type) is basically a DC instrument. This meter movement can be made so sensitive that a few microamperes of current will swing the pointer across the entire scale. If the pointer and zero indication are placed at the center of the scale, the movement can be used for making accurate resistance, capacitance, and inductance measurements in bridges and can be modified for such use as a DC ammeter or a voltmeter. It can be made to measure AC by applying the AC to the meter

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through a suitable rectifier and measuring the rectified current.

11-4. Because this meter movement is rugged, accurate, and capable of measuring DC voltages and current, AC voltage, and also resistance, it is used in the multimeter. The multimeter is a combination volt-ohm-milliameter.

11-5. **Sensitivity.** Meter sensitivity can be defined in two ways, as the amount of current necessary for full-scale deflection and as ohms-per-volt. Sensitivity may vary from 5 microamperes to approximately 50 milliamperes; and the smaller the amount of current necessary for full-scale deflection of the meter, the greater the sensitivity. The sensitivity in ohms-per-volt is determined by the amount of resistance that must be placed in series with the meter to cause full-scale deflection when an EMF of 1 volts is applied.

11-6. Overshooting and the tendency of the pointer to oscillate are overcome by a process known as *damping*. As the coil rotates, a CEMF is generated in the nonmagnetic shell upon which the coil is wound. The currents resulting from this CEMF produce a magnetic field that opposes the field established by the moving coil. The net result of the two opposing fields is to slow down the turning rate of the moving coil and make it possible for the coil to reach the proper position without overshooting or oscillating.

11-7. **Ammeter.** An ammeter is designed to measure current, and it must be connected in series with the circuit so that all the current passes through it. This also means that in order to prevent an appreciable decrease in circuit current the total resistance of the ammeter must be low. In actual practice, it is often necessary to measure currents that are greater than the full current range of a given meter. To permit these measurements, it is necessary to use the laws of parallel circuits and connect a low resistance conductor in parallel with the meter. When used for this purpose, the low resistance conductor is called a shunt and it becomes a part of the ammeter.

11-8 When the ammeter, consisting of the meter and shunt in parallel, is connected in series with the circuit, the current will divide so that the moving coil and the shunt will each carry a proportionate part. Like any parallel circuit, the current in the two paths is proportional to the resistance of the branch Therefore, by proper selection, a shunt can be found that will carry any desired portion of the total current. Since this proportion between meter current and shunt current always remains the same, the meter scale can then be calibrated to indicate the total current, although the moving coil carries only a portion of it.

11-9. Current-measuring instruments must always be connected in *series* with a circuit and never in parallel with it. If an ammeter were connected across a constant-potential source of appreciable voltage, the shunt would become a short circuit and the meter would burn out.

11-10. If the approximate value of current in a circuit is not known, it is best to start with the highest range of the ammeter and switch to progressively lower ranges until a suitable reading is obtained.

11-11. Most ammeter needles indicate the magnitude of the current by being deflected from left to right. If the meter is connected with reversed polarity, the needle will be deflected backwards, and this action may damage the movement. Hence the proper polarity should be observed in connecting the meter in the circuit. That is, the meter should always be connected so that the meter terminals are connected to like polarities in the circuit.

11-12. **Voltmeter.** Voltmeters are designd to measure electrical pressure, and the scale is calibrated directly in terms of volts. The D'Arsonval, or moving-coil, meter may be used in the construction of a voltmeter. However, there are a few things to be considered. In the first place, voltage is a difference in potential between two points; and to measure it, the meter must be connected directly across the two points.

11-13. A second factor to be considered is that the coil of the meter is moved by the magnetic effect of an electrical current. Because the resistance of the coil is purposely kept low, the current must not be allowed to exceed that required for full-scale deflection. A voltmeter thus operates because of the current through it, but the scale is calibrated to indicate, not the current, but the voltage necessary to cause the current in the coil.

11-14. The 100-microampere D'Arsonval meter used as the basic meter for the ammeter may also be used to measure voltage if a very high resistance is placed in series with the moving coil of the meter. For low-range instruments, this resistance is mounted inside the case with the D'Arsonval movement. Typically, this resistance consists of a resistance wire having a low-temperature coefficient and wound either on spools or card frames. For higher voltage ranges, the series resistance may be connected externally. When this is done, the unit containing the resistance is commonly called a *multiplier*.

11-15. Multirange voltmeters use a single meter movement with the multiplier resistance connected in series with the meter by a con-

venient switching arrangement. The total circuit resistance for each of three ranges (1, 100, and 1000 volts) beginning with the 1-volt range may be found by dividing the voltage by the current (in microamperes) which gives the resistance in megohms as follows:

$$R = \frac{E}{I} = \frac{1}{100} = 0.01 \text{ megohm}$$
$$= \frac{100}{100} = 1 \text{ megohm}$$
$$= \frac{1000}{100} = 10 \text{ megohms}$$

11-16. *Sensitivity*. The sensitivity of a voltmeter is given in ohms per volt (Ω/V). The sensitivity can be increased by increasing the strength of the permanent magnet, by using lighter weight materials for the moving element (consistent with increased number of turns on the coil), and by using sapphire jewel bearings to support the moving coil.

11-17. *Accuracy*. The accuracy of a meter is generally expressed in percent. For example, consider a meter that has an accuracy of 1 percent of the correct value. The statement means that if the correct value is 100 units, the meter indication may be anywhere within the range of 99 to 101 units.

11-18. *Voltmeter connections*. Voltage-measuring instruments are connected *across* (in parallel with) a circuit. If the approximate value of the voltage to be measured is not known, it is best to start with the highest range of the voltmeter and lower the range progressively until a suitable reading is obtained.

11-19. In many cases, the voltmeter is not a central zero indicating instrument. Thus, it is necessary to observe the proper polarity when connecting the instrument to the circuit, as is the case in connecting the DC ammeter. The positive terminal of the voltmeter is always connected to the positive terminal of the source, and the negative terminal is connected to the negative terminal of the source when the source voltage is being measured. In any case, the voltmeter is connected so that electrons will flow into the negative terminal and out of the positive terminal of the meter.

11-20. The function of a voltmeter is to indicate the potential difference between two points in a circuit. When the voltmeter is connected across a circuit, it shunts the circuit. If the voltmeter has low resistance, it will draw an appreciable amount of current. The effective resistance of the circuit will be lowered, and the voltage reading will consequently be lowered.

11-21. When voltage measurements are made in high-resistance circuits, it is necessary to use a high-resistance voltmeter to prevent the shunting action of the meter. The effect is less noticeable in low-resistance circuits because the shunting effect is less.

11-22. **Electrodynamometer Applications.** The electrodynamometer type meter differs from the D'Arsonval type meter in that no permanent magnet is used. Instead, two fixed coils are used to produce the magnetic field. Two movable coils are also used in this type meter.

11-23. *Voltmeter*. When used as a voltmeter, no difficulty in construction is encountered, because the current required is not more than 0.1 ampere. This amount of current can be brought in and out of the moving coil through the springs. When the electrodynamometer is used as a voltmeter, the fixed coils are wound with fine wire since the current through them will be no more than 0.1 ampere. They are connected directly in series with the movable coil and the series current-limiter resistance. For ammeter applications, however, a special type of construction must be used, because the large currents that flow through the meter cannot be carried through the moving coils.

11-24. *Ammeter*. In the ammeter the stationary coils are generally wound of heavier wire to carry up to 5 amperes. In parallel with the moving coils is an inductive shunt, which permits only a small part of the total current to flow through the moving coil. This current through the moving coil is directly proportional to the total current through the instrument. Because the shunt has the same ratio of reactance to resistance as has the moving coil, the instrument will be reasonably correct at all frequencies with which it is designed to be used.

11-25. The meter is mechanically damped by means of aluminum vanes that move in inclosed air chambers. Although electrodynamometer type meters are very accurate, they do not have the sensitivity of the D'Arsonval type meter.

11-26. We have covered applications of meter movements for voltage and amperage measurements. Now let's consider their use for resistance measurement.

11-27. **Measuring Resistance.** The two instruments most commonly used to check the continuity or to measure the resistance of a circuit or circuit element are the ohmmeter and the megger (megohmmeter). The ohmmeter is widely used to measure resistance and check the continuity of electrical circuits and devices. Its range usually extends to only a few megohms. The megger is widely used for measuring insulation resistance, such as between a wire and the outer surface of

its insulation, or such as insulation resistance of cables and insulators. The range of a megger may extend to more than 1,000 megohms.

11-28. *Ohmmeter.* The ohmmeter consists of a DC milliammeter, as discussed earlier in this chapter, with a few added features. The added features are as follows:

- A DC source of potential (usually a dry cell battery).
- One or more resistors (one of which is variable).

11-29. The ohmmeter's pointer deflection is controlled by the amount of battery current passing through the moving coil. Before measuring the resistance of an unknown resistor or electrical circuit, the test leads of the ohmmeter are first shorted together. With the leads shorted, the meter is calibrated for proper operation on the selected range. (While the leads are shorted, meter current is maximum and the pointer deflects a maximum amount somewhere near the zero position on the ohms scale). When the variable resistor (rheostat) is adjusted properly, with the leads shorted, the pointer of the meter will come to rest exactly on the zero graduation. This indicates ZERO RESISTANCE between the test leads, which, in fact, are shorted together.

11-30. The zero readings of series type ohmmeters are sometimes on the right-hand side of the scale, whereas the zero reading for ammeters and voltmeters is generally to the left-hand side of the scale. When the test leads of an ohmmeter are separated, the pointer of the meter will return to the left side of the scale due to the interruption of current and the spring tension acting on the movable coil assembly. After the ohmmeter is adjusted for zero reading, it is ready to be connected in a circuit to measure resistance.

11-31. The power switch of the circuit to be measured should always be in the OFF position. This prevents the circuit's source voltage from being applied across the meter, which could cause damage to the meter movement. The test leads of the ohmmeter are connected across (in series with) the circuit to be measured. This causes the current produced by the meter's battery to flow through the circuit being tested. The amount of current that flows through the meter coil will depend on the resistance of resistors plus the resistance of the meter. Since the meter has been readjusted to zero, the amount of coil movement now depends solely on the resistance of the circuit under test. The pointer will come to rest at a scale figure indicating the combined resistance of the circuit being tested. Movement of the moving coil is proportional to the amount of current flow. The scale reading of the meter, in ohms, is inversely proportional to curernt flow in the moving coil.

11-32. The amount of circuit resistance to be measured may vary over a wide range. In some cases it may be only a few ohms, and in others it may be as great as 1,000,000 ohms. To enable the meter to indicate any value being measured, with the least error, scale multiplication figures are incorporated in most ohmmeters. For example, a typical meter will have four test lead jacks marked as follows: COMMON, R × 1, R × 10, and R × 100. The COMMON jack is connected internally through the battery to one side of the moving coil of the ohmmeter. The jacks R × 1, R × 10, and R × 100 are connected to three different size resistors located within the ohmmeter. Therefore, the meter must be "zeroed" for each scale.

11-33. Some ohmmeters are equipped with a selector switch for selecting the multiplication scale desired so that only two test lead jacks are necessary. Other meters have a separate jack for each range. The range to be used in measuring any particular unknown resistance depends on the approximate ohmic value of the unknown resistance.

11-34. It always takes the same amount of current to deflect the pointer to a certain position on the scale (midscale position, for example) regardless of the multiplication factor being used. Since the multiplier resistors are of different values, it is necessary to always "zero"-adjust the meter for each multiplication factor selected. You should select the multiplication factor that will result in the pointer coming to rest as near as possible to the midpoint of the scale. This enables you to read the resistance more accurately, because the scale readings are more easily interpreted at or near midpoint.

11-35. When you use the ohmmeter, take care to avoid connecting the ohmmeter across circuits in which a voltage exists, since such a connection can result in damage to the meter. Although the power switch normally performs the function of removing applied voltage from the equipment, the switch itself can be defective. Therefore, to insure the removal of all voltage to the equipment under test, disconnect the source of input voltage by removing the power plug. Batteries or bias cells to provide fixed bias or other operating voltages may be included in the circuits under test, and the ohmmeter must not be connected across these sources of voltage. All capacitors must be discharged before the ohmmeter prods are connected in the circuit, since charges remaining on capacitors after the applied voltage has been removed can damage the meter severely. Because the resistance of

circuit elements in a heated condition may differ considerably from that in a cool state, it is advisable to wait a few minutes after the power has been removed before applying the ohmmeter to the equipment.

11-36. When resistance measurements are made in a circuit, each element can be tested individually by removing it from the circuit and connecting the ohmmeter test prods across it. However, this method consumes time, and usually measurements are made from various points in the circuit to a selected common reference point (chassis or ground). In this manner, complete sections of the circuit can be measured quickly to determine the presence of abnormal conditions. Charts indicating *point-to-point resistance values* usually are supplied with the equipment. The ohmmeter is connected across the designated points, and the readings obtained are compared with those on the chart. When an abnormal resistance reading is obtained, each element in the circuit is isolated and tests are made to determine the cause of the abnormality.

11-37. To avoid erroneous readings when no resistance chart is available, care must be taken to ascertain that other circuit elements are not connected in parallel with the element being measured. The element under test usually can be isolated by opening one of its connections in the circuit.

11-38. A leaky capacitor connected in parallel with a resistor under test can pass current and will indicate a resistance reading, depending on the degree of leakage. The reading obtained on the ohmmeter is the resultant of the circuit resistance and the parallel leakage resistance of the capacitor. With a leaky capacitor in the circuit, a reading is obtained even if the shunt resistor is completely open, and it is necessary to disconnect one end of the circuit element before taking a measurement.

11-39. The hands of the technician should not come in contact with the metal tips of the test prods. The resistance of the human body under certain conditions is low, less than 50,000 ohms, and may cause erroneous readings. This is particularly noticeable when a high resistance is being measured. *All resistance measurements should be made with the hands holding the insulated* portions of the test prods.

11-40. The ohmmeter can check roughly the condition of capacitors and determine the presence of short circuits or leakage. When you test capacitors, other than electrolytics, turn the ohmmeter selector switch to the highest range, since this provides the highest source of voltage available in the ohmmeter. Observe the meter closely and connect the test prods to the capacitor. With a good capacitor, the meter pointer deflects slightly and returns quickly to the infinite-ohms position as the capacitor charges across the ohmmeter battery. Small values of capacitors cause a slight deflection of the meter pointer and return quickly to the infinite position; larger values cause a greater deflection, and a longer time is taken for the pointer to return. However, if the capacitor is good, the meter pointer will return to the infinite-ohms position in a relatively short time. If no deflection is obtained, an open capacitor is indicated or the capacitance of the unit is too small to cause a deflection. A full-scale deflection of the pointer indicates a shorted capacitor, and leakage is indicated by a steady deflection on some part of the scale. The resistance of a paper capacitor should be over 50 megohms per microfarad, and that of a mica capacitor should be over 100 megohms per microfarad.

11-41. When testing electolytic capacitors, set the ohmmeter to the high range and connect the prods across the capacitor. Because current passes more readily through the electrolytic capacitor in one direction than in the other, care must be taken to observe polarity or the reading obtained will be incorrect. When the prods are connected to the capacitor, a large deflection occurs on the meter, then the pointer returns slowly toward the infinite-ohms position as the capacitor takes a charge. Usually, some reading is obtained even when an electrolytic capacitor is fully charged. For a good capacitor rated at 450 working volts DC, the final ohmmeter reading should be over 500,000 ohms. Low-voltage electrolytic capacitors should read at least 100,000 ohms to be acceptable.

11-42. *Megger.* You cannot use an ordinary ohmmeter for measuring resistance of multimillions of ohms, such as conductor insulation. To adequately test for insulation breakdown, it is necessary to use a much higher potential than is furnished by an ohmmeter battery. This potential is placed between the conductor and the outside surface of the insulation.

11-43. The megger is a portable insulation-resistance test set for measuring large values of electrical resistance. It consists of a high-range ohmmeter and a hand-operated DC generator mounted in the same case. The resistance range of the megger usually extends from 0 to 1000 megohms or more, and the ohmmeter is of special design. The generator may deliver a potential of 500, 1000, or 2000 volts at the test terminals, but in military applications a 500-volt DC generator is generally used.

11-44. When the crank of the megger is operated, the DC generator produces a 500-volt

DC potential. Connected across the generator output is a potential coil. The magnetic field set up by the current through the potential coil reacts with the field set up by a permanent magnet in such a way that the coil and pointer assembly move in a counterclockwise direction. With no external circuit connected to the test set, the pointer indicates infinite resistance on the scale.

11-45. When a circuit of unknown resistance is connected to the tester, it forms a parallel circuit with the potential coil. Also, connected in series with the external circuit is a current coil that is part of the ohmmeter movement. The magnetic field set up by the current through the current coil tends to move the pointer (clockwise) to the 0 position on the scale.

11-46. This meter is called a true or differential ohmmeter because the position of the pointer is determined by the difference between two forces. One force, the current coil, tends to move the pointer toward 0. The other force, the potential coil, tends to move it toward infinity. The system comes to rest at a point where the two forces are balanced; the position depends on the value of the unknown resistance. This position does not depend on the voltage generated within the equipment, as in an ordinary ohmmeter.

11-47. The DC generator is operated by a hand crank through a gear train and clutch assembly. The clutch mechanism slips when a certain speed of hand-crank rotation is reached, and this keeps the generator at a constant operating speed. Therefore, the output voltage will be fairly constant as long as the crank is rotated above the speed at which the clutch slips.

11-48. Before connecting the megger to the equipment to be tested, all power should be disconnected. Because of the small amount of torque and the lack of balance springs in the movement, the megger should be kept in an upright position and placed away from strong external magnetic fields so that the reading is not affected. The test leads are then connected to the megger and the megger tested for leakage. With the test lead open, the meter should read infinity; when the test leads are short-circuited, the meter should read zero.

11-49. Finally, the test leads are connected to the device whose insulation resistance is to be checked. The handcrank then is rotated until the clutch slips and the meter reading becomes steady. A reading is taken which is compared with the proper value of insulation resistance. It is important that the insulation resistance be measured at the same temperature every time an insulation test is made because the resistance of insulation drops sharply at high temperatures. For example, the insulation resistance between the stator winding of a certain slow-speed generator and the frame is 100 megohms at 85° F. The insulation resistance of this same equipment falls only to 10 megohms at 140° F.

11-50. This concludes our discussion on the individual meters. Next, we discuss a combination of the milliammeter, ohmmeter, and voltmeter into one compact unit, which we call a multimeter.

11-51. **Multimeters.** A multimeter is an instrument incorporating two or more meter circuits and a meter movement in a single case. A typical multimeter contains voltmeter, milliammeter, and ohmmeter circuits using a single meter movement. They may, however, be designed for many specific applications, such as measuring resistance, capacitance, AC volts, and DC volts. The multimeter described in this section is used for voltage, current, and resistance measurements.

11-52. To select the proper circuit for measuring voltage, current, or resistance, either a rotary selector switch or a set of pin jacks is mounted on the instrument panel. The rotary selector switch consists of many sections (wafers) of insulating material with switch contacts attached. Each position on the switch corresponds to a particular measuring circuit in the instrument. When the switch is in the DC voltage position, for example, a contact on each wafer of the switch connects a particular element (meter movement, resistor network, or shunt) into the measuring circuit. In many multimeters, two rotary switches are used, one selecting the measuring circuit and the other the range.

11-53. For simplicity of reading, a multimeter has three scales. There is one for resistance measurements, one for DC volts and milliamperes, and one for AC volts. The scales usually are provided with a single set of calibration marks and with one or more sets of numerals at the major marks or divisions. Figure 38 is a typical meter face.

11-54. *AC instruments.* Most of the AC measurements in electrical and electronic circuits are now made with a DC moving-coil meter using a rectifier to convert the AC to DC before it is applied to the meter movement. Typical of this type of meter is the TS-297/U, which you carry in your toolbox, and the AN/PSM-6, which is used around the shop. These rectifier type instruments provide us an AC meter with relatively high ohms-per-volt ratings.

11-55: *Copper-oxide rectifier.* The most commonly used rectifier is the copper-oxide type. This rectifier may be a single unit or consist of a group of individual rectifiers connected together. The simplest unit, used in less sensitive instru-

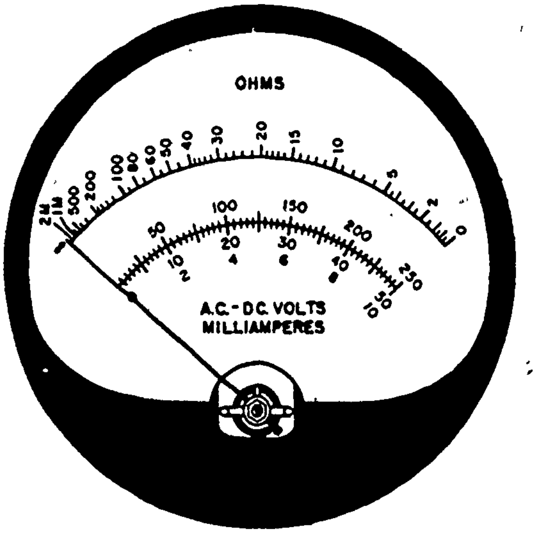

Figure 38. Resistance, AC, and DC scale of a typical multimeter.

ments, is the single half-wave rectifier. This arrangement permits current flow through the meter only during one-half of the cycle, and blocks current flow to the meter during the other half of the cycle. The most sensitive arrangement uses a bridge rectifier. When the source of the measured voltage has one polarity, one set of rectifiers conduct; and when the source has the opposite polarity, the other set of rectifiers conduct. This full-wave rectification results in a current flow through the meter in the same direction for both half-cycles. The average value of the pulsating DC through the meter is approximately twice as great as that achieved with half-wave rectification. The meter response with full-wave rectification is doubled, and the meter's sensitivity is improved by the same ratio.

11-56. AC meters are calibrated so that they read the rms value of the sine wave of the voltage or current being measured. The moving coil cannot follow the instantaneous changes of pulsating dc because of its inertia.

11-57. **Vacuum-Tube Voltmeters.** A vacuum-tube voltmeter is an instrument for measuring AC or DC voltages and it uses one or more vacuum tubes in a special circuit containing a meter. The operating power for the tubes is usually obtained from a built-in power supply working off an AC line, but batteries can be used. Different types of probes are used with the instrument for measuring AC voltages to very high values and over a wide band of frequencies. The VTVM is also known as an *electronic voltmeter*.

11-58. The primary advantage of the VTVM over ordinary meters is its ability to measure voltages without loading the circuit. Normal operating conditions are left more or less undisturbed since the VTVM draws negligible current from the circuit under test. This is of special advantage in solid state circuits where the conventional voltmeter changes the circuit conditions and produces false readings.

11-59. The VTVM can be used to measure ac voltages over a frequency range extending from 5 to 10 cycles to several hundred megacycles. Specially designed instruments have an upper frequency limit of several thousand megacycles and can be used for testing high-frequency equipment.

11-60. The VTVM can be used to measure low voltages in high-impedance circuits, since the input impedance of the VTVM usually is standardized at approximately 10 megohms. The loading effect is negligible when this impedance is placed in shunt with the circuit under test, and low voltage can be measured with a high degree of accuracy. The conventional meter, having much lower input impedance on the low-voltage ranges, loads the circuit and produces erroneous readings.

11-61. **Basic VTVM.** The basic DC VTVM circuit consists of a triode, a source of plate voltage, a source of grid bias, and a DC milliammeter calibrated to read the plate current resulting from the voltage applied between the grid and cathode of the tube. No current flows through the tube with a zero input voltage, and the meter in the plate circuit indicates zero. When a voltage is applied to the input terminals, plate current flows through the circuit and is indicated on the meter in the circuit.

11-62. In order to make the input resistance of the instrument high, a high-resistance voltage divider is used. The taps on the voltage divider are arranged so that a wide range of dc voltages can be measured. Regardless of the range, the maximum voltage applied to the grid circuit should never be more than 8 volts in order to limit the meter to its full-scale deflection. Each voltage range has its own tap on the voltage divider applied to the grid. Each voltage range is indicated on its own scale. Note that the total divider resistance represents the input impedance or total resistance of the instrument.

11-63. These fundamentals just discussed never change. However, their applications in the various VTVMs that you may encounter involve many variations in the circuitry. Most modern instruments make use of two or more tubes connected to form a bridge circuit.

11-64. The meter indication corresponds to the average value of the input voltage. The meter scale can be calibrated to read average, rms, or peak values.

11-65. The frequency range of the instrument can be greatly extended by rectifying the AC voltage to be measured before applying it to the DC amplifier. A special test probe may be used to house the rectifier diode or the rectifier may be within the instrument case, in which case the conventional probe can be used for the AC measurements.

11-66. The AC scales of VTVMs are normally calibrated to indicate the rms value of a sine wave voltage. Therefore, when voltages having other than a sine waveform are to be measured, true measurements cannot be made unless the VTVM measures peak-to-peak values, as well as the rms of effective values. The peak-to-peak measurements are accurate only on sine wave voltages, and the P–P scale is calibrated to indicate 2.828 times the rms value. This multiplication factor will not result in true values on other than sine waves.

11-67. When you service modern electronic systems, it is frequently necessary to accurately measure the peak-to-peak values of irregular waveforms. The VTVM designed to do this incorporates a voltage doubler circuit for the purpose of making these P–P measurements. These units are easily identified by the separate P–P positions on the selector switch. There may, or may not, be a separate meter scale for the P–P values. If not, the regular AC scales are used.

11-68. The meter scales cover a wide range of AC and DC voltages and resistance values. Each scale is different from the others in some detail. There are also variations in the scales used by different manufacturers and even variations in different models made by the same manufacturer. All of these scales are essentially the same, and they are designed to be used in the same way. Most errors occur when reading the value indicated and those can be avoided by following these three steps:

- Determine the proper scale to be used.
- Read the value indicated on that scale.
- Use the multiplier or scale indicated by the RANGE SELECTION switch.

11-69. **Wattmeter.** Electric power is measured by means of a wattmeter. This instrument is of the electrodynamometer type. It consists of a pair of fixed coils, known as current coils, and a movable coil, known as the voltage coil.

11-70. The actuating force of a wattmeter is derived from the interaction of the magnetic field of the current coil and the magnetic field of the voltage coil. The force acting on the moving coil (voltage coil) at any instant is proportional to the product of the instantaneous values of line current and voltage.

11-71. The wattmeter consists of two circuits, either of which will be damaged if too much current is passed through it. This fact is especially emphasized in the case of wattmeters, because the reading of the instrument does not serve to tell the user that the coils are being overheated. If an ammeter or voltmeter is overloaded, the pointer will be indicating beyond the upper limit of its scale. In the wattmeter, both the current and the potential circuits may be carrying such an overload that their insulation is burning, and yet the pointer may be only part way up the scale. This is because the position of the pointer depends upon the power factor of the circuit as well as the voltage and current. Thus, a low-power factor circuit will give a very low reading on the wattmeter even when the current and potential circuits are loaded to the maximum safe limit. The safe rating is generally given on the face of the instrument. This rating is not given in watts but in volts and amperes.

11-72. **Watt-Varmeter.** In those installations where more than one AC generator is used to furnish the electrical power, it is vitally important that each furnish its share of the real (KW) and the reactive (KVAR) load if maximum performance and service life are to be expected from the system. The real (KW) and reactive (KVAR) loads present in an aircraft AC power system will be explained in detail in this course. The watt-varmeter is used to provide a visual indication of the amount of useful power in watts and of the nonuseful or reactive power in VARs in the AC power system.

11-73. This meter uses the electrodynamometer type meter movement. A switch is incorporated into the meter circuit to facilitate using the instrument to indicate either true power or reactive power. The pointer deflection is determined by the torque produced by the two currents. If the current and the voltage are in phase, the product of current times voltage at any instant will be maximum and the pointer deflection will also be maximum. If the current and voltage are out of phase, the product of voltage and current at any instant will be less than maximum, causing a proportionally smaller deflection of the pointer. Once the meter scale has been properly calibrated, it will read the true power of the circuit.

11-74. When using the same instrument to measure the reactive power (KVARs), a phase-shifting capacitor is used. Such an arrangement will not respond to the components of current

and voltage that are in phase in the AC line to which it is connected, but will respond to that component of line current that is out of phase with the normal line voltage. The same calibration on the meter that was previously used to obtain true power will now indicate the amount of reactive power in the circuit.

11-75. **Power-Factor Meter.** One definition of the power factor of a circuit is the ratio of true power to apparent power. This is not the only definition. It is also equal to the cosine of the phase angle between the circuit current and voltage. A pure resistance has a power factor of unity (the current and voltage are in phase and the true power and the apparent power are the same). A pure inductance has a power factor of zero (current lags the voltage by 90°), and a pure capacitance has a power factor of zero (current leads the voltage by 90°). The cosine of 90° is zero. The power factor of a circuit may be determined by the use of a wattmeter, a voltmeter, and an ammeter—that is, the power factor may be determined by dividing the wattmeter reading by the product of the voltmeter and ammeter readings. This is inconvenient, however, and instruments have been developed that indicate continuously the power factor, and at the same time indicate whether the current is leading or lagging the voltage. An instrument that indicates these values is called a power-factor meter.

11-76. **Frequency Meters.** In some AC systems it is necessary to know the frequency of the voltage source. Two types of frequency meters are suitable for this purpose. These are the dynamometer type frequency meter, which uses the electrodynamometer principle, and the vibrating reed type meter, which is an electromechanical type of instrument.

11-77. *Dynamometer type frequency meter.* The dynamometer type frequency meter uses a dial and pointer to provide a visual indication of the frequency being measured. The commonly used frequency meter is the type A-1, which includes a basic dynamometer type of frequency meter circuit.

11-78. Such a meter can be calibrated to read the exact frequency directly. In this system the current does not increase at a uniform rate but increases more rapidly as resonance is approached. Therefore, this type of meter can be used for only a small frequency range.

11-79. *Vibrating reed type frequency meter.* The vibrating reed type meter contains an electromagnet mounted near a metal plate. When the electromagnet is energized with AC, vibrations are set up that are identical in period with the flux reversals caused by the alternating current in the coil. The vibrations are transmitted to a metal plate, part of which consists of a set of carefully balanced metal reeds. Each reed is turned to vibrate excessively at one particular frequency. If more than one reed is vibrating, the one vibrating the most indicates the nearest correct frequency.

11-80. *Frequency counter.* The counter type of frequency meter, also called the digital-frequency meter, is a high-speed electronic counter, with an accurate, crystal-controlled time base. This type of combination provides a frequency meter which automatically counts and displays the number of events or cycles occurring in a precise time interval in the form of digits.

11-81. This type of frequency meter permits the rapid measurement of frequency without involved interpolation or the possibility of ambiguous results. The measurement of a large number of different frequencies in quick succession is also easily accomplished. The counter type of frequency meter is also independent of input waveform, since the input signal is eventually shaped into a series of pulses recurring at the same frequency as the input frequency.

12. Special Purpose Measuring Devices

12-1. Many of the measurements you will be required to take are difficult to do with a common meter. For this reason many special-purpose measuring devices have been developed. Some of the most used are discussed in this section.

12-2. **Use of the Oscilloscope.** Figure 39, a simplified block diagram of a typical oscilloscope, shows the general electrical location of some of the oscilloscope controls. The ON-OFF switch (not shown) and the focus and intensity controls are located in the power supply section which is connected to the electron gun.

12-3. In most of the oscilloscopes, the ON-OFF switch connects the various power supplies of the oscilloscope to the ac power source, and the intensity control varies the voltage which controls the number of electrons leaving the electron gun. After turning on the "scope," turn the intensity control down to keep from burning the CRT (cathode ray tube) screen. The focus control changes the voltage which compresses the stream of electrons into a narrow beam so that the stream will form a small dot or trace on the fluorescent screen. After the CRT is warmed up, a small clear dot or a thin line should appear in the center of the screen if all of the controls are properly set. You should then adjust the focus and intensity controls for a sharp clear line or dot.

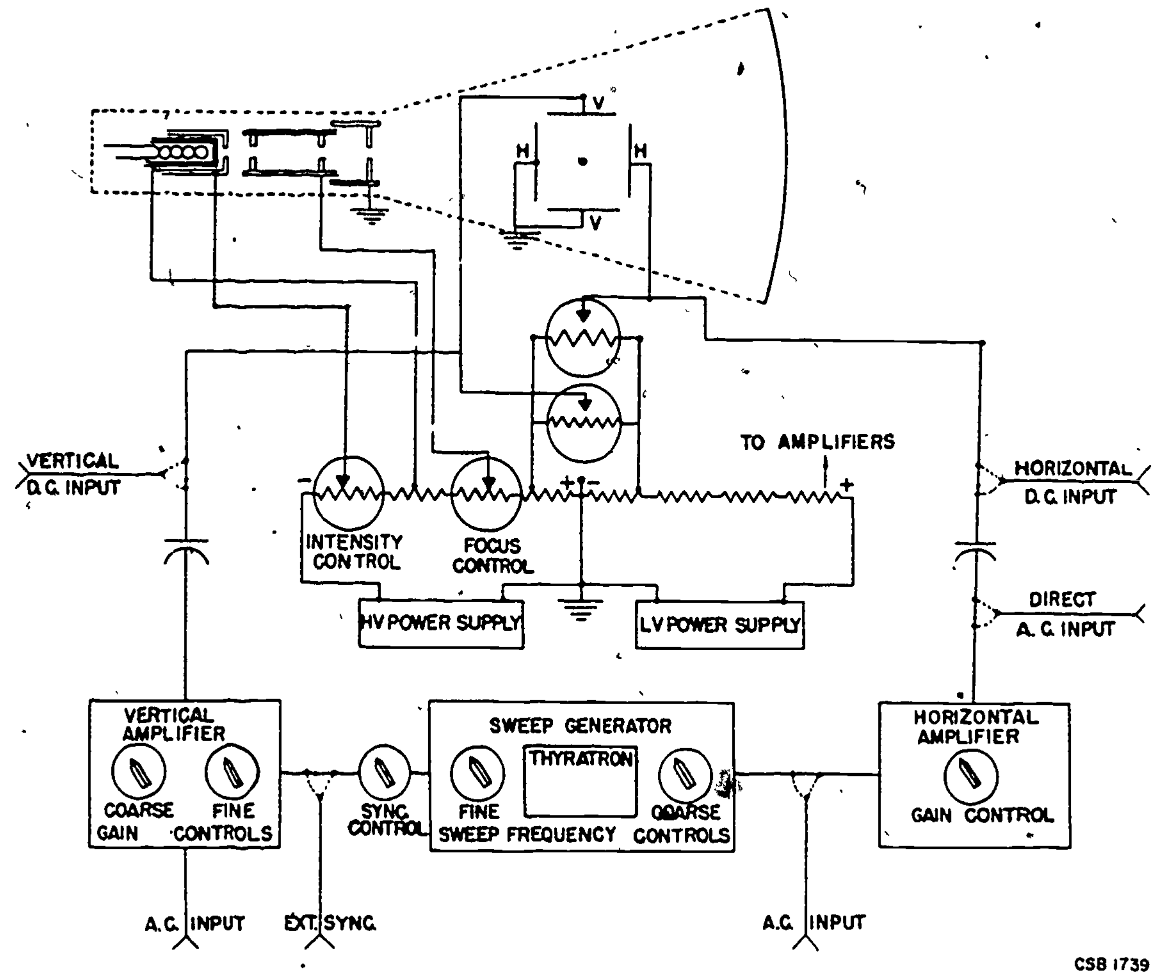

Figure 39. Block diagram of a typical CRT oscilloscope.

12-4. The horizontal and vertical position (centering) controls are used to move the electron beam across or up and down the screen. Each of the controls is actually a potentiometer. From the block diagram in the figure, you can see that each potentiometer is used to vary a direct current potential which is applied to one of each of the deflection plates. If the DC potential on the deflection plate is made more negative, the beam is repelled. If too high a potential is applied, the beam may be moved so far that no dot will appear on the screen. These controls should be left in a position where the image is centered.

12-5. You use two adjusting knobs on the scope to control the sweep frequency. The first (sweep-range selector) is marked either "coarse frequency" or "frequency range" and it has several positions. At each position of this switch the approximate range of frequencies for the sweep generator will be indicated. Usually, this control inserts electronic circuit components of various sizes into the circuit to give a fairly large change in frequency of the sweep generator as the selector is moved from one position to another.

12-6. The second control knob for the sweep generator is the vernier or fine-frequency control. It varies the frequency smoothly over each range. By operating both controls together, you can sweep the dot at speeds varying from a few times a second up to many thousands of times a second. These two controls should be used in conjunction to synchronize the scope sweep and the AC input signal.

12-7. The length of the sweep can be changed by varying the horizontal gain control. The control does not change the electrical length of the sweep, or the time base, on the scope. Instead, it changes only the physical length of the sweep. Therefore, with the frequency control set so that 1000 microseconds are required for the dot to travel from one end of the time base to the other, that amount of time will elapse whether the horizontal gain is at zero or at maximum. With this

control turned all of the way counterclockwise, the horizontal time base line is decreased to zero, and the beam appears only as a dot. When you turn the control clockwise, the line is made longer. It is possible to stretch the time base line beyond the visible ends of the screen so that only a small portion of the sweep is actually visible on the screen. This is useful when only a small portion of a wave shape must be examined closely.

12-8. The remaining controls on the scope affect the sweep. One is the sync select switch, which has at least these three positions: EXTERNAL, INTERNAL, and LINE. Another is the sync control which regulates the amplitude of the synchronizing voltage. Sometimes it is difficult to confine the sweep generator to the exact frequency which will maintain a stationary image on the screen. If a voltage of the desired frequency and amplitude is fed into the sweep circuit, it will lock the sweep generator at the frequency. This synchornizing voltage may originate within the scope itself or may come from the 60-Hz line voltage that is fed to the scope. It may also come from an external source, such as from the signal being observed.

12-9. When the signal to be observed is extremely small, it is not fed directly to the vertical deflection plates. Instead, it is first amplified until it gives a strong enough response. Two controls, the vertical amplifier ratio (VAR) and the vertical gain (VG), are used to alter the size of the image on the screen. The VG and VAR controls are not found on all oscilloscopes.

12-10. The ability of the scope to give a stationary pattern for a changing voltage represents one of its most valuable functions. Different components within a circuit have different effects on waveshapes. With the aid of the oscilloscope, these effects can be identified from the shape of the waves.

12-11. The scope can be used to determine an unknown ac frequency. Before it can do this, however, the sweep frequency must be known. With the sweep frequency known, the unknown signal frequency may be found by making a few simple computations.

12-12. If the frequency of the signal is known, the sweep frequency can be determined by direct observation of the pattern that appears on the screen. These procedures are applicable only if there is a simple relationship between the frequencies of the two voltages. Some very interesting patterns called Lissajous patterns may be obtained by applying an AC signal to the horizontal deflection plates at the precise moment another AC signal voltage is applied to the vertical deflection plates. Figure 40 shows the results

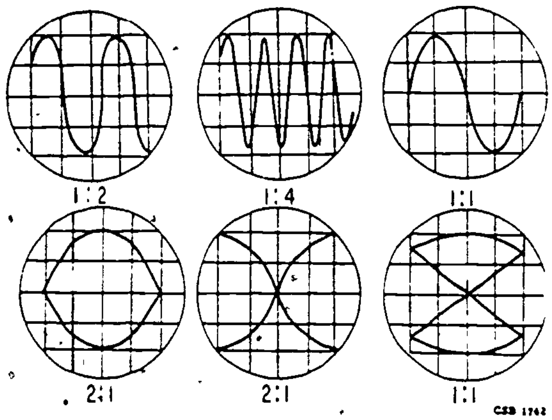

Figure 40: Sweep patterns.

of applying voltages of the same frequency to the two pairs of plates. The circle at the upper left shows the image that is formed on the screen when two identical voltages (E_1 and E_2) having the same frequency, the same amplitude, and the same starting time for their cycles are applied to the two pairs of plates. The result is a straight line directed at an angle of 45° with respect to a horizontal plane. Unequal amplitudes having the same frequency produce straight lines at different angles. Since voltages E_1 and E_2 are going through the same cycle simultaneously (in time with each other), they are said to be in phase.

12-13. Two voltages of the same frequency may begin their cycles at different times. Such voltages are said to be out of phase. If one voltage reaches its maximum positive value when the other voltage is at zero and starting in a positive direction, they will be 90° out of phase. In this instance the first voltage is said to lead the second voltage by 90°. The result of applying two such voltages is shown in the upper right pattern in the figure. Voltages E_3 and E_2 are of the same amplitude and the same frequency, but E_3 leads E_2 by 90°.

12-14. The scope pattern in the lower left corner of the figure shows the result when the voltage on the vertical deflection plates is of the same frequency but of a smaller amplitude and 90° out of phase with the voltage on the horizontal deflection plate. Voltage E_4, in this case, lags E_1 by 90°. The resultant image on the screen is in the form of an ellipse.

12-15. In the circle in the lower right-hand corner of the figure you can see what happens when two voltages have the same frequency but different amplitudes and are 180° out of phase when applied to the two pairs of deflection plates. The image appears as a straight line whose angle with respect to the horizontal reference plane is

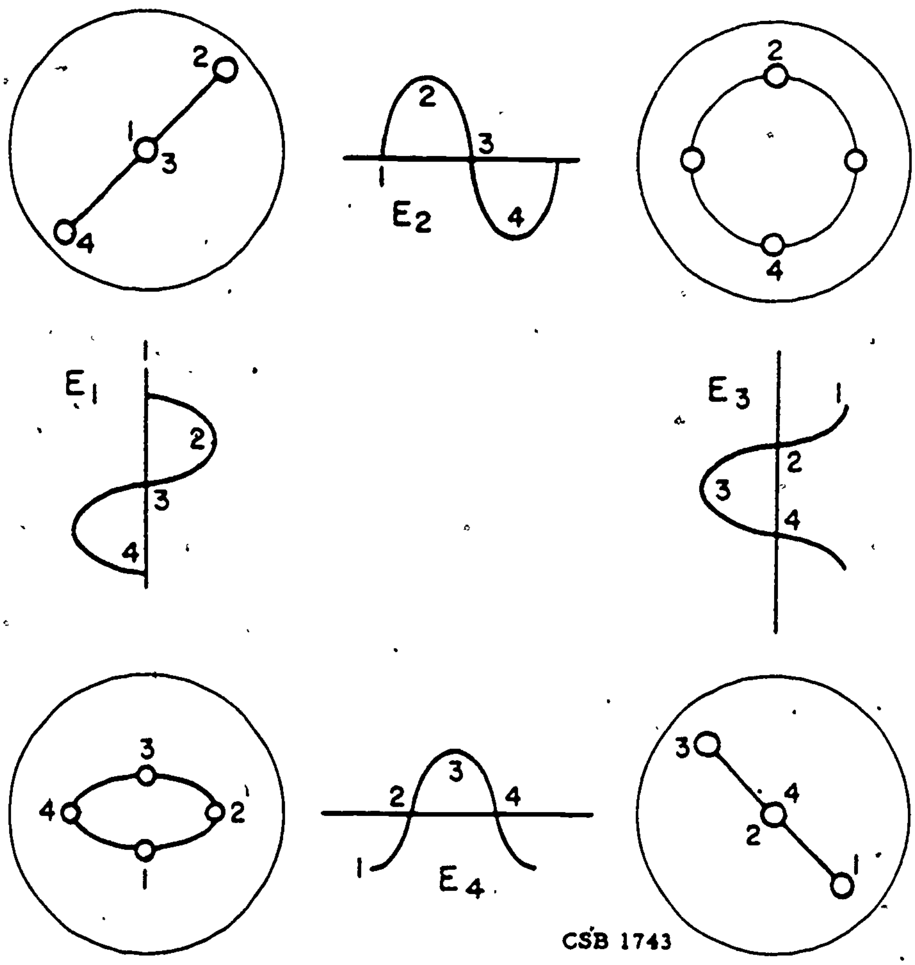

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Figure 40. Sweep patterns.

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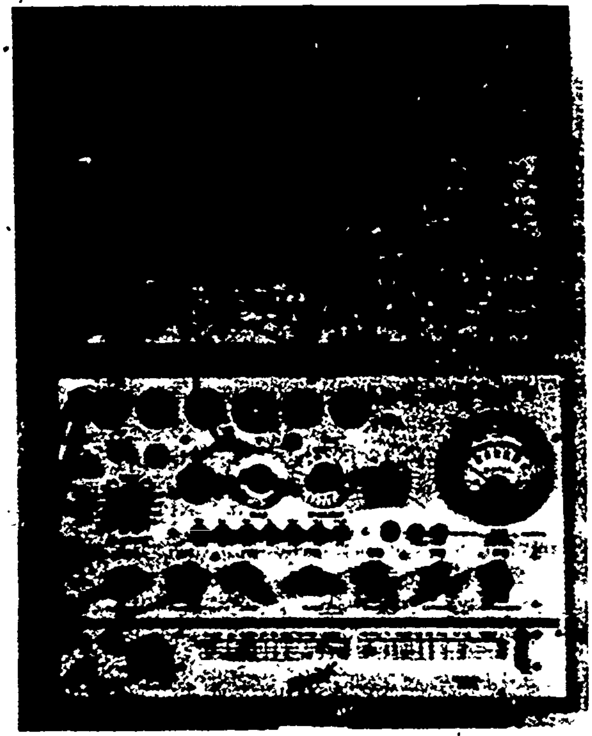

Figure 41. Transconductance type tube tester.

the result of the ratio of the respective amplitudes of the voltages concerned.

12-16. At this point you should be familiar with the waveform of a normal sine wave; therefore, the remainder of this section will discuss the patterns of distorted sine waves which you may encounter and the causes of these distortions. We are using the term "distortion" in a very loose manner to generally signify dissatisfaction with the shape of the sine wave processed by an amplifier. Bear in mind that the waves of all amplifiers are not the same, and what is a normal waveform for one amplifier may be an abnormal waveform for another amplifier. Always check the applicable technical order for the particular item of equipment you are testing so that you may compare the waveform displayed on the oscilloscope with the waveform that is desired.

12-17. When you are examining a waveform in a class A amplifier circuit, you are generally looking for a smooth curve in which the positive and negative peaks are identical. Any distortion, however slight, can usually be considered due to some malfunction in the circuit. Often this is a malfunctioning tube. Let's discuss how we test tubes!

12-18. **Tube Testing.** Each tube is tested by the manufacturer before it is packaged and shipped to the dealer. Since the tubes may be damaged during transit, storage, or handling, they should be tested before they are used. Tubes that are in service do not last forever. Failure is commonly attributed to one of the following reasons: (1) the cathode may lose its ability to emit electrons because its coating flakes off, (2) the tube may develop a leak and permit air to enter the envelope, and (3) internal shorts or opens may occur as a result of excessive voltages and/or vibrations while in service. In brief, there are many ways for the tube to become defective. A tube that glows is not necessarily good, and you cannot check it merely by looking at it.

12-19. The only sure method for you to check the condition of a tube is with a tester. Most of these units are portable and are about the size of a small suitcase. They require an external source of 115-volt, 60-cycle power for operation. Although there are many models, they all fall into two general classifications, emission and transconductance testers. The transconductance type, which is shown in figure 41, provides the most accurate means of testing. A tube may indicate normal emission and still not operate properly, because the tube efficiency depends on the ability of the grid voltage to control the plate current. The emission tester does not check this factor, but it does check the plate current. By contrast, the transconductance machine measures the grid-plate transconductance and indicates the operation of the tube, not just the condition of the emitting surface. In addition, tube testers of all kinds usually provide a check for shorts, noise, and gas.

12-20. Figure 41 illustrates a typical transconductance type tube tester. This illustration is provided only to show the general appearance of a typical unit. In a unit such as this, the operating instructions are located on the inside of the cover, as shown.

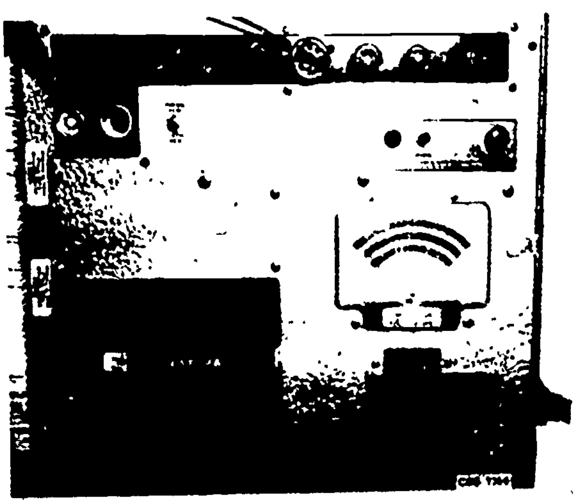

Figure 42. Semiautomatic tube tester.

12-21. The ON-OFF switch shown in the lower left-hand corner of the illustration connects the tester to a 110-volt power line. It should be in the OFF position while the various controls are being set for the particular tube to be tested. The LINE ADJUST knob is used to compensate for differences in the line voltage that would affect the reading on the meter. The roll charts, located at the bottom of the tester, list the settings for the tube that is to be tested, and the knobs located directly above the roll charts are set at the levels indicated by the charts. By comparing the information on the roll charts with the reading indicated on the meter, you can determine the serviceability of almost any electron tube that you may encounter. In addition, the tester also provides a control for determining shorts within the tubes.

12-22. Another type tube tester is shown in figure 42. This tester is known as a semiautomatic tester because the roll charts and the adjusting controls have been replaced by a prepunched plastic card for the particular tube to be tested. When the card is inserted into the holder, the card actuates a microswitch which, in turn, actuates all the desired circuits simultaneously. The meter indicates the serviceability of the tube. The card is released from the holder by operating the PUSH-TO-REJECT-CARD knob, which releases the card and disconnects all the circuits. In addition, the tester contains test cards that can be used to determine the location of defective meter shunt resistors and calibration cards to calibrate various potentiometers within the test unit. Provisions are also made so that replacement cards or new cards may be punched as required.

12-23. This has been a very brief discussion of tube testers. This course is not intended to teach you the operation of special pieces of equipment. By following the directions supplied with the tube testers, you will encounter little difficulty in testing electron tubes; however, let us mention one *precaution*. Before the tube to be tested is inserted in the correct test socket, you should make certain that the front-panel controls are set to the positions listed for that type of tube in the data chart. This precaution is necessary to prevent excessive voltages from being applied to the tube elements (especially the filament).

12-24. *Line-voltage adjustment*. The line-voltage adjustment is necessary so that the line voltage applied to the primary of the transformer can be preset. It is preset to an operating value of 93 volts (used as a test reference point) regardless of the variations caused by different tube loads or fluctuations in the AC supply, which may range from 105 to 130 volts and still be adjustable. The test equipment is calibrated at the factory so that the meter pointer rests over the LINE TEST mark (approximate center) when the voltage across the primary is 93 volts. Since various types of electron tubes draw different values of currents, a LINE ADJUSTMENT rheostat is provided so that the primary voltage can be set to the designed operating voltage before any test is begun. A small protective lamp that will burn out on an overload is connected in series with the primary of the transformer to prevent equipment damage.

12-25. *Short-circuit test*. By means of a rotary five-position switch labeled SHORT TUBE TEST, the electrodes of the tube under test are switched, in turn, across a neon SHORTS lamp that is connected in series with the secondary of the transformer. Shorted tube elements (and any other internal tube connections) will complete the AC circuit, which causes both plates of the neon lamp to glow. Momentary flashes of the neon SHORTS lamp may be caused when the switch is rotated. These flashes are caused by the charging of the small interelectrode capacitances of the tube when the voltage is applied and do not indicate short circuits. If the tube under test has a shorted element, the neon lamp will glow continually on one or more switch positions. Since the filament circuit and other internal tube connections will show up as short circuits in this test, the tube data chart should be consulted for pin connection information before interpreting the results of the test.

12-26. *Noise test*. The circuit that is used to check for short circuits is also used to determine the noise condition of the tube under test. In tests for noise, the antenna and ground terminals of a radio receiver are connected to the NOISE TEST receptacles. Any intermittent short between tube electrodes permits the AC voltage from the power transformer to be applied momentarily to the neon lamp. The brief oscillation caused by the firing of the lamp contains radio frequency noise signals which are amplified, detected, and reproduced as audio signals by the associated radio receiver. A less sensitive noise test can be made using a pair of headphones instead of the radio receiver. To cause movement of loose electrodes, you can tap the tube during this test.

12-27. *Gas test*. Two pushbutton switches, labeled GAS No. 1 and GAS No. 2, are used for this test. The GAS No. 1 button is first depressed, and the plate-current reading on the meter is noted. Depressing the button marked GAS No. 2 inserts a 180,000-ohm resistor into the grid circuit. If gas is present in the tube, the

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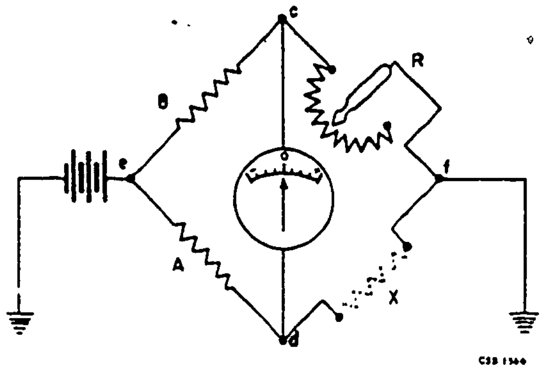

Figure 43. Simple bridge circuit.

grid current that flows reduces the normal bias on the tube and increases the plate current measured by the meter. A tube with a negligible amount of gas produces an increase in plate current of less than one scale division when the GAS No. 2 button is depressed. An increase of more than one scale division indicates an excessive amount of gas in the tube.

12-28. *Rectifier test.* Diode rectifier and detector tubes are checked by the same method used in the emission type tube tester. A known value of AC voltage is applied to the tube under test, and the meter indicates the rectified plate current. The two sections of full-wave rectifier are tested separately. The switch for testing OZ4 cold-cathode rectifier tubes provides a higher AC voltage than is normally used for filament type rectifier tubes. The switch for diode tubes provides a lower voltage than that used for regular rectifier tubes, and also inserts a protective series resistor.

12-29. *Quality test.* For the quality test of grid controlled tubes, a meter scale calibrated in arbitrary units is used. The minimum acceptable reading is listed in the tube data chart. The correct value of this grid bias is obtained when the BIAS control resistor is rotated to the setting listed in the tube data chart. An AC voltage is applied in series with the grid bias. This signal causes the grid potential to change from the DC bias level, thereby producing the grid-voltage change required for a dynamic transconductance test. The plate voltage for the tube under test is supplied by a rectifier tube. A meter that indicates the plate-current change is in the return circuit of the rectifier supply. A dual potentiometer is used to adjust the resistance shunted across the meter so that a single meter scale can be used for testing any of the tubes listed in the tube data chart. Another special tester is the Wheatstone bridge, a special resistance tester.

12-30. **Wheatstone Bridges.** The Wheatstone bridge is a network circuit generally used to measure resistance. It is far more accurate than the D'Arsonval ohmmeter. Generally speaking, the bridge is used only where resistance must be known to a fraction of an ohm. Therefore, for other cases, instruments that have a circuit similar to the Wheatstone bridge are used.

12-31. One of these, the simple bridge circuit shown in figure 43, consists essentially of a sensitive galvanometer, a source of EMF, two fixed resistors (A and B), and a variable one (R). This circuit, which will serve to introduce you to the Wheatstone bridge, operates on the balance of voltage between points in a parallel circuit. You can read the value of the resistance being measured (X) directly from the rheostat knob, which controls a very accurately calibrated variable resistor.

12-32. The bridge operates in the following manner. BR and AX form a parallel circuit between points e and f, and the voltage across each branch is equal to the applied voltage. In order for current to flow in a conductor, a difference in potential (EMF) must exist between the two points to which it is connected.

12-33. To balance the Wheatstone bridge, the terminals of the galvanometer (c and d) must be at the same potential. For this condition, the voltage across R must equal that across X, and the potential across B must equal that across A. Since A and B have the same resistance, that of R must correspond to X in order for the bridge to be balanced. By changing the resistance of R until the galvanometer indicates no current flow, you can read the value of X in ohms from the calibrated knob of the rheostat (R).

12-34. Although a bridge of the type explained is extremely accurate, it has a small range of capability because of the single variable resistor. By making A and B variable, you can increase the range many times while retaining the same accuracy. You can do this because the ratio of any two adjacent resistors in a balanced circuit is equal to that of the other two. This statement can be summarized by the following equations:

$$\frac{A}{B} = \frac{X}{R}, \frac{B}{R} = \frac{A}{X}, \text{ or } X = \frac{A \times R}{B}$$

Since the values of A, B, and R are known, you can calculate the value of X. Now that you have studied the simple circuit for background, let's go over a temperature measurement unit, which is an airborne installation that uses a typical Wheatstone bridge.

12-35. There are 100 ohms in the thermometer resistance of the sensitive element when its temperature is at some predetermined value.

Since the resistance arms (A, B, and C) are set for 100 ohms, the circuit is in equilibrium, and no current flows through the coil of the D'Arsonval meter mechanism. When the bulb temperature increases or decreases, so does its resistance; but the resistances of the other arms are fixed. Since the equilibrium is destroyed, the current flows through the coil of the D'Arsonval meter and causes it to rotate between the poles of the permanent magnet. As a result of this effect, the pointer moves to indicate the increase or decrease of temperature. Since the possible error owing to variations of supply voltage is least near mechanical zero, this point is on the portion of the scale where the greatest accuracy is needed. Specifically, this is where the pointer always comes to rest when the power supply is turned off.

Advanced Physics for the Electrician

WHAT IS WORK? Before work can be defined, we must know what force is. Force is defined as energy exerted. This simply means that if for some reason energy is directed, then it is force. This concept can be shown in a more realistic situation. We have all seen a ball thrown into the air, and observed the ball fall back to the ground. This is an example of force. Energy in the form of gravity is the force that pulls the ball back to the ground.

2. Armed with the knowledge of force, we can now define work, but work is not simply the application of force. Work is the transfer of energy from one object to another. More simply stated, if a resistance is overcome by a force and if movement results in a measurable distance, then work is done. An example of work is pushing a broom. Energy is transferred from the arm to the broom handle and brush; if the energy level (force) is sufficient, the brush will slide over the floor, guiding the dirt in the direction of brush movement. This example is typical of work in the Air Force because energy is transformed to accomplish an objective. In this example, the objective is a clean floor.

3. Imagine, if you will, cleaning the floor beneath you with *no* tools! This task would take forever, and you would never become an electrician. Fortunately, we have tools to lessen our labor. These tools come in many different forms. We can be more general and call this applied physics.

13. Applied Physics

13-1. Three methods of applied physics that interest us are simple machines, effects of pressure and temperature on a material, and electron physics. The first of the applied physics we will discuss is the simple machine.

13-2. **Simple Machines.** Usually a machine is thought of as a complex unit—an engine or an adding machine. True, these are machines, but so are other simpler devices such as crowbars, screwdrivers, or steering wheels. *A machine is any device that helps you do work. Machines do not lessen the amount of work to be done; they only make the job easier to do. A machine may help a man do a job by changing the amount of force or the speed of the action that he uses.* For example, a clawhammer is a machine. It can be used to apply a large force. A relatively small pull on the handle produces a much greater force at the claws than is possible without leverage. In many ways, man can increase the force he applies. Some of these ways are complicated, but even the complicated ways are only combinations of two or more simple machines. A simple machine is a unit that cannot be broken down into more simple elements and still work.

13-3. How can we tell when a machine is doing an efficient job? Measuring input and output is the method used. We call this measurement mechanical advantage.

13-4. *Mechanical advantage.* This is an expression of the ratio of the resistance and the applied force. When a force is used to overcome a larger resisting force, a mechanical advantage is said to exist. The mechanical advantage of force may be determined by either of the two formulas:

$$MA = \frac{\text{effort distance}}{\text{resistance distance}}$$

Or

$$MA = \frac{\text{resistance}}{\text{effort}}$$

13-5. All simple machines, or combinations thereof, are used, primarily, to change direction or size of an available force. This change makes the force more useful in doing work on a resistance. The ratio resulting between the resistance and the effort is the mechanical advantage.

13-6. It is impossible to make a machine 100 percent efficient. But some machines are more

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efficient than others. Friction is the main factor limiting the efficiency; however, friction is a necessary evil.

13-7. Many machines are a combination of two or more simple machines. The mechanical advantage of a compound machine is usually the product of the separate mechanical advantages. If one machine with a mechanical advantage of 5 and a second machine with the same advantage were combined, a mechanical advantage of 25 would result for the unit.

13-8. We know that a machine should decrease the amount of work. Let's look at an example.

13-9. *The screw.* The screw is a simple machine that has many uses. Examples of the application of the screw are the vise on a workbench, the screw clamps used to hold pieces of furniture together while they are being glued, and the jackscrew used in lifting an airplane.

13-10. The screw is a modification of the inclined plane, used in conjunction with a lever. Cut a sheet of paper in the shape of a right triangle. Wind it around a pencil, as in figure 44, foldout 1. (Note to student: Figs. 44–101 can be found on foldouts 1–7 at end of volume.) This experiment shows that the screw is actually an inclined plane wrapped around a cylinder. The distance between threads is called the pitch. Pitch is measured along the length of the screw.

13-11. Study figure 45, foldout 1. There you see a jackscrew. It is the type used to raise a house or a piece of heavy machinery. The jack has a lever handle. As the handle is pulled around one turn, its outer end completes a circle. That is the distance through which effort (F) is applied. At the same time, the screw has made one revolution, and has been raised a height equal to its pitch (h-P). One full thread has come out of the base and the load has been raised a distance equal to the pitch of screw.

13-12. The theoretical mechanical advantage of the screw is equal to the ratio of the distance traveled by the end of the lever to the distance between the threads of the screw. The formula is

$$MA = \frac{2\pi \cdot R}{P}$$

in which R equals the length of the handle and P equals the pitch of the screw.

13-13. If the length of the lever arm is 24 inches and the pitch of the threads is ¼ inch, what is the mechanical advantage?

$$MA = \frac{2 \times 3.14 \times 24}{1/4} = \frac{150.72}{1/4} = 602.88$$

A 50-pound force on the handle would result in a lift of 50 × 602, or about 30,000 pounds.

13-14. Keep in mind, however, that the foregoing equation is only theoretical. Actually, the counter force of friction cuts down the mechanical advantage to a considerable degree, thus necessitating more force than the equation indicates. A high friction loss is present in any jack because the threads are so cut that the portion of the applied force used to overcome friction is actually greater than the portion used to do useful work. If the threads were not cut this way, the weight of the load would cause the jack to spin back down to the bottom as soon as the force is released.

13-15. In a jack, a lot of circular motion is used to get a small amount of straight-line movement from the head of the jack. As with all machines, the actual mechanical advantage equals the resistance divided by the applied effort.

13-16. Friction, though a hindrance in doing work, is present in every motion or movement. It is a factor which lowers the efficiency and mechanical advantage of a machine.

13-17. Simple machine principles are used throughout modern aircraft. Every system has one or more of the simple machines, such as the lever, pulley, wheel and axle, inclined plane, wedge, and screw.

13-18. None of these are mysteri[illegible] You will encounter them in your everyday duties. If you recognize and understand them, your job will be easier.

13-19. This is not the only applied physics that concerns an electrician. Not all objectives can be accomplished using simple machines to perform work. Forces of pressure and temperature applied to a material can be harnessed to do work in many aircraft systems.

13-20. **Effects of Pressure and Temperature.** Matter is a substance that has space and weight. But, what does that have to do with pressure and temperature? Well, anytime matter changes form—gas, liquid, or solid—energy is released or absorbed. Of course, when the state of matter is altered, the volume of the matter changes form. Do you recall that a transfer of energy is work? The above statement thus implies that work is being done. The first effect discussed is pressure.

13-21. *Pressure.* Did you ever try to walk on crusted snow that broke through under your weight? Unless snowshoes are used, you know it is impossible to walk on thin-crusted snow without breaking through. The snowshoes do not reduce your weight—they merely distribute it over a larger area. By doing this, the snowshoes re-

duce the pressure. Pressure is the push or pull per unit area of the surface acted upon. In the Air Force, pressure is normally measured in pounds per square inch (psi). In the example above, if you weigh 160 pounds, that weight or force is more or less evenly distributed by the soles of your shoes. The area of the soles of an average man's shoes is roughly 60 square inches. Each one of those square inches has to carry 160 ÷ 60, or 2.6 pounds of your weight. Since 2.6 pounds per square inch is too much for the snow crust, you break through.

13-22. But, put on the snowshoes. Your weight now is distributed over an area of 900 square inches—depending, of course, on the size of the snowshoes. Now the forces on each of those square inches is 160 ÷ 900, or only 0.18 pound. The pressure per unit area on the snow has been decreased, and the snow can support you.

13-23. Visualize the previous examples; and instead of ice, use water or even steam. The example won't work; liquids and gases have different properties than solids. This is illustrated by the bourdon tube principle.

13-24. A common pressure switch works on the principle of a bourdon tube. A volume of air is forced through a small tube at high speed with low pressure. Then the air is dumped into a chamber where speed drastically decreases and pressure increases until the diaphragm moves and actuates the switch. The example in the following paragraph will illustrate the operation of this principle.

13-25. Refer to figure 46, foldout 1. Notice that the switches normally have open electrical contacts when no differential air pressure is applied and closed electrical contacts when the air pressure is sufficient. The HI port (B) on the pressure switch leads to a high-pressure source. The LO side port (A) of the pressure switch is vented to the atmosphere. When enough air is available for operation, the diaphragm (C) is forced upward and the microswitch (D) is closed. This action completes the electrical circuit. When the air pressure drops below what it should be for operation, the diaphragm moves downward and the microswitch opens the electrical circuit.

13-26. Pressure is used in many systems on an aircraft, and you must understand pressure physics to successfully troubleshoot these systems. Another force of physics is the change in temperature of a material.

13-27. *Temperature.* We have all seen ice melt, water boil, and steam condense. These examples are results of heat application. By definition, the above action is work. Energy is being transferred from the heating source to the material being heated. But, most electricians are not concerned with water on an aircraft, so let's look for a different example of temperature effects.

13-28. A continuous cable fire warning system operates on the transfer of energy because of heat application. The transfer takes place in the sensing element. What happens when heat is increased around the sensing element?

13-29. Two conducting materials are separated by a porous ceramic insulating material that is impregnated by a substance that reacts drastically to heat application. The whole operation depends on the impregnated substance within the makeup of the sensing element.

13-30. At a predetermined point the impregnated substance changes from a solid material to a liquid material. As a result the liquid substance will duct through the pores in the ceramic and complete a low resistance path for current flow between the two conductors (inside and out). The reverse is true when the heat is removed from the sensing element.

13-31. When the heat is removed, the liquid condition will revert back to a solid and that consequently breaks the circuit. Why? As the temperature of the substance decreases, cohesion will become the major force and the volume of the impregnated substance decreases. When the transfer of energy is from the impregnated material to the surrounding air, electrons around the nucleus of atoms of the impregnated substance become more dependent upon the cohesion force than upon an outside influence, such as temperature.

13-32. We have seen that physical changes of a material can be put to work, but another type of physics exists that interests an electrician above the level of simple machine, pressure, and temperature effects. Of course! ELECTRON PHYSICS.

13-33. **Electron Physics.** You may well wonder what can be discussed under electrical principles, and specifically electron physics, that you can use in your work. Let's try to explain how these two subjects are related to your job.

13-34. As an aircraft electrician, you will be troubleshooting complicated electrical systems. These complicated systems very often contain transistors or other semiconductor devices. To properly troubleshoot these systems, you must understand how and why the semiconductors operate or you will not be able to properly interpret the indications of the test instruments you are using. To understand semiconductors you must first understand the nature of matter. Even though you may remember some parts of this subject from your 3-level schooling, we shall re-

view the material to insure that all students begin at the same point.

13-35. *Atomic Structure.* All matter—solid, liquid, and gas—is composed of *molecules*. The molecules, in turn, are composed of *atoms*. Each of the hundred-odd known elements of matter is composed of atoms that are different from the atoms of the other elements. They differ in the number of *subatomic* particles which they contain. Three major subatomic particles are the *proton, neutron,* and *electron*. The electron is the most important to you as an electrician. The relationship between the subatomic particles can best be described as *electron physics*.

13-36. Let's take a closer look at the behavior of electrons surrounding the nucleus. Refer to figure 47, foldout 1.

13-37. The protons and neutrons together form the nucleus of an atom around which the electrons circulate, much like planets around the sun. The electrons are negative charges of electricity, and the protons are positive charges of electricity. In the normal or balanced atom, the number of electrons equals the number of protons. The electrons are held in their orbits by the attraction that exists between unlike charges.

13-38. Let's consider an atom of the element carbon, Figure 48, foldout 1. The carbon atom contains six positive protons in its nucleus and six negative electrons in orbit. The charges cancel out, so the atom is *electrically neutral*.

13-39. Note that an atom is electrically neutral when it contains the same number of positive charges in the nucleus as it has negative charges in orbit. Most atoms are electrically neutral. If they are not neutral, they are called *IONS*.

13-40. An example of an ion is found in figure 49, foldout 1. There are four protons, but only three electrons. The three negative charges do not cancel the four positive charges, so the atom is not neutral. It is an ION.

13-41. Another example is found in figure 50, foldout 1. Again, there are four protons, but now there are five electrons. This too, is an ION.

13-42. It should be of more than passing interest for you to note there is a difference between the two ions. Figure 49, foldout 1, has four protons (+), and three electrons (−). Therefore, *having one more positive than negative charge,* it is a *positive ion*. Figure 50, foldout 1, has four protons, and five electrons. It has an *extra negative charge* and is, therefore, a *negative ion*.

13-43. When it was in its neutral state, the atom in figure 49, foldout 1, contained four protons and four electrons. Obviously, then, it had to *lose* one electron in order to arrive at its present state of being a positive ion. Likewise, the atom in figure 50 had to *gain* one electron to arrive at its present state of being a negative ion.

13-44. It follows that in order for an atom to become an ion, it is *considered to either have lost or gained electrons from its outer orbit*. The outer orbit isn't the only orbit that can lose or gain electrons. However, it is the only one we are concerned with at this time.

13-45. The *OUTER ORBIT* is the orbit that is farthest from the *nucleus*. The electrons in this outer orbit are called *valence electrons*. Valence refers to the *position* of an electron with respect to its nucleus.

13-46. Perhaps you're wondering where the "lost" electrons go and where the "gained" electrons come from. Obviously, when they go some place or come from some place, there is movement involved. This movement of electrons is electric current and will be discussed in following paragraphs.

13-47. Now, let's concentrate on valence electrons (see fig. 51). In some substances these electrons are easy to move from their orbit. Normally, they are moved from their orbit by the force of another electron entering that orbit. They may move from one atom to another in a haphazard manner. Electrons that are able to move in this fashion are known as free electrons. The atomic structure of a material will determine whether or not the material has many or few free electrons.

13-48. In general, all materials may be placed in one of the following three major categories: *conductors, semiconductors,* or *insulators*. These categories were evolved from a consideration of their ability to allow an electric current to flow. This, in turn, depends on their atomic structure.

13-49. *Conductors.* A good conductor is a material that has a large number of free electrons. The free electrons move from atom to atom in a haphazard manner. (Refer to figure 52, foldout 1.)

13-50. The movement is approximately equal in all directions so that electrons are not lost or gained by any particular part of the conductor. When this random movement of free electrons in a conductor is controlled so that the electrons move generally in the same direction, an electron flow results. This electron flow is called an electric current.

13-51. It takes quite a while to talk about it, but the effect of the electron movement is felt instantaneously from one end of the conductor to the other. A good conductor, then, permits free electrons to move through it. In so doing, it permits a current to flow.

13-52. A significant effect upon the action of the free electrons is temperature. What happens when the temperature of a material increases? The volume of the material has to increase, and the free electrons move farther apart. Therefore, a constant force distributed over a greater area will decrease the rate at which the free electrons flow, and consequently, work is decreased. This principle is known as a positive temperature coefficient and is prevailing in all metals.

13-53. Conductors may be in the form of bars, tubes, or sheets, but the most common conductors are in the form of wire. The ability of a material to conduct electricity also depends upon its dimensions. This will be covered in a later discussion. In order to make wire easier to handle and also less subject to changes in weather and other external conditions, it's often covered with some other material such as rubber, plastic, or enamel. These coverings also provide protection against short circuits and leakage. The coverings are known as insulators and will be the second of the three major categories we'll discuss. Remember, the three major categories were conductors, semiconductors, and insulators. The categories were evolved from a consideration of the material's ability to allow electric current to flow. This, in turn, depends upon their atomic structure.

13-54. *Insulators.* An insulator is a material or combination of materials, the atomic structure of which opposes the movement of electrons from atom to atom. In other words, an insulator is a material that has few loosely held electrons. No material known is a perfect insulator, but there are materials that are such poor conductors that for all practical purposes they are classed as insulators. Glass, *dry* wood, rubber, mica, and certain plastics such as polystyrene are materials that are good insulators.

13-55. Now, let's review what has been covered in this discussion. We defined a conductor in terms of its atomic structure. A good conductor is a material that has a large number of free electrons. Silver, copper and aluminum are materials with many free electrons. Copper is the most commonly used. In terms of its atomic structure, an insulator is a material with a very small number of free electrons. Rubber, mica, glass, *dry* wood and plastics are examples of good insulators.

13-56. *Semiconductors.* Between the extremes of good conductors and good insulators are a number of materials that are neither good conductors nor good insulators. Germanium and silicon fall into this category and are called semiconductors. An important characteristic of semiconductors is that they are composed of atoms whose valence electrons can be readily shared with another adjacent atom of the same material. For example, germanium, the most common semiconductor material, has four valence electrons that can be readily shared with another germanium atom. The result is that when many germanium (or other semiconductor material) atoms are close together, the valence electrons will tend to form *covalent bonds.*

13-57. A covalent bond is formed when two adjacent atoms share an equal number of valence electrons. The bond is maintained by the attracting force of one atom's nucleus on the other atom's electrons, although there is no change in the chemical or electrical characteristics of either atom. Only substances that have a crystalline structure have the ability to form covalent bonds.

13-58. A specific difference between semiconductors and the other two categories is that of heat effect. Normally, a substance will increase its opposition to current flow as temperature increases, but a semiconductor will decrease its opposition to current flow with an increase in temperature. Reason behind this principle is discussed in greater detail in the next chapter.

13-59. Let's look at a part of electrical physics that deals with static charges.

13-60. **Electrostatics.** As we continue into the area of charged bodies, keep in mind that we are dealing with *electrostatics.* The study of electrostatics is actually the study of *electrical charge at rest.* It is here that the electrical forces between particles can be observed experimentally and measured *before motion begins.* The fundamental laws that govern these forces can be derived and stated.

13-61. Let's take an example. A "pith ball" (fig. 53,A, foldout 1) is a substance containing many thousands of atoms. If the atoms are all neutral, then the substance is also neutral. However, if you take away some electrons, the substance becomes positively charged. Add electrons and it becomes negatively charged. A substance (fig. 53,B, foldout 1) may be in any one of three electrical conditions. The conditions are *positive, negative* or *neutral.*

13-62. Remember the basic law of electrical charges? Like charges repel each other; unlike charges attract each other. See figure 53,C, foldout 1.

13-63. Charged substances either attract or repel each other, since their charges must be alike or unlike. Consider a pith ball that is positively charged. Place it near one which is negatively charged and they will attract each other. If the charges are great enough and the balls are free to move, they will come into contact. Even if the balls are not free to move, a force of attraction

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exists between them because of their unlike charges. This attraction takes place because the excess electrons of the negative charge are trying to move to the positive charge, which has a deficiency of electrons. The attraction is felt through the electric field of the protons and electrons in the pith ball. An electric field is composed of the unseen lines of force which radiate in all directions.

13-64. A force of repulsion always exists between like charges due to their electric fields. Thus, if a moving electron comes close to another electron, the second electron will be pushed away without the two electrons coming into contact. The force of this repulsion between like electrostatic charges, or attraction between unlike charges, is related to the distance between the charged bodies. This can be shown by the following formula:

$$f = \pm \frac{Q_1 \times Q_2}{d^2}$$

where f = force (in dynes)
Q_1 = charge on body 1
Q_2 = charge on body 2
d^2 = distance squared (in centimeters)
$\pm$ is used because the force can be either attraction or repulsion

13-65. Let us inject a cheerful note about this formula. You don't have to be too concerned with it at this time. We are only using it to show you the relationship between distance and force in charged bodies. However, it should bring an important point to your attention. The point is that the charges on a body (Q_1 and Q_2) are measurable. Indeed they are. The unit of electrical charge is the coulomb. The coulomb is a definite quantity of electrons.

13-66. *Coulomb*. There are many electrons in a coulomb of electrical charge. Specifically, one coulomb contains 6.28×10^{18} electrons, which is 6.28 million, million, million electrons. The coulomb measures the quantity of the electrical charge (number of electrons) regardless of whether the charge is in motion or standing still. The law of electric charges may be extended to explain other important phenomena.

13-67. *Friction*. Let's take a look at how substances may be charged and the distribution of the charges on the substance. Friction is the most common method of producing a static charge. We use two examples. Rub a glass rod with a piece of silk and the friction produces a static charge on the rod. Rub a rubber rod with a piece of cat's fur and again the friction produces a static charge on the rod. Arbitrarily, we call the charge on the glass positive and that on the rubber negative.

13-68. *Conduction*. Another method is through conduction. If you should touch a positively charged rod to an uncharged metal bar, it will attract electrons in the bar to the point of contact. Some of these electrons will leave the bar and enter the rod, which causes the bar to become positively charged and decreases the positive charge of the rod. See figure 54 on foldout 2. The transfer of static charge through actual contact is known as conduction.

13-69. *Induction*. Suppose that instead of touching the bar with the rod, you only bring the positively charged rod near to the bar. In this case, electrons in the bar are attracted to the point nearest the rod, which causes a negative charge at that point and a positive charge at the other end. See figure 55 on foldout 2.

13-70. By allowing electrons from an outside source (your finger, for instance) to enter the positive end of the bar, you can give the bar a negative charge. The bar has become charged even though the rod did not touch it. This is known as the induction method of charging a substance. See figure 55 on foldout 2.

13-71. This discussion covered the normal conditions of an electric charge at rest. What happens when the charge is put in motion is our next subject.

13-72. **Electrodynamics.** In a previous discussion a conductor was defined in terms of its atomic structure. It was stated that a good conductor is a material with many free electrons. An interesting point was made about electron characteristics. The electric field around an electron causes it to repel other electrons without actually touching the other electrons. Now, let's take a good conductor and pay particular attention to the free electrons in it. For an example, let's use an automobile battery as our source of electrons, see figure 56 on foldout 2. Chemical action inside the battery has caused electrons to pile up on the negative terminal. A conductor is connected to this terminal.

13-73. *Current flow*. When the random movement of free electrons in a conductor is controlled so that the electrons move generally in the same direction, an electron flow results; this electron flow is called an electric current. Obviously, our battery in figure 56, foldout 2, has caused a current flow through the conductors. The electrons have moved from the negative terminal through the conductors, and back to the battery through the positive terminal. Actually, this movement of electrons occurs simultaneously throughout the conductor.

13-74. Try not to think of the current flow as shown in figure 56 on foldout 2 in terms of an individual electron leaving the negative terminal, moving around the conductor and back into the positive terminal, but rather as a chain reaction which takes place throughout the entire conductor. At the time that one electron was leaving the negative terminal, a free electron was pulled off the conductor by the positive terminal. The net effect is felt instaneously between the terminals and throughout the conductor.

13-75. This is the basis of the electron theory. Electrons always move from positive to negative inside a battery and from negative to positive in the external circuit. Since there is a difference in the quantity of electrons between the two battery terminals, we can say a *potential difference* exists. If a *conductor* is connected between the terminals, the excess electrons on the negative post flows toward the positive post, where there is a shortage of electrons. In order to have *electron flow*, there must be a *potential difference*. Electron flow is a quantity of electrons moving through a conductor and is measured in coulombs.

13-76. *Amperage*. There are 6.28×10^{18} electrons in one coulomb. By counting the coulombs which pass in a given length of time, the current flow is measured. The unit of current flow is the *ampere*. One ampere of current is flowing when one coulomb of electrons passes through the material in 1 second; two amperes when two coulombs pass per second, etc.

13-77. Since amperes mean coulombs per second, *the ampere is the rate* at which electrons are moving through a material. The *coulomb*, which represents the number of electrons in a charge, *is a measure of quantity*. The symbol for current is "I."

13-78. *Voltage*. As has already been discussed, the modern concept of electricity regards current as a flow of electric charges. Free electrons move about the interior of the substance, continually having their direction changed by collisions with other electrons and atoms. Each electron produces an electrical and magnetic field when it moves, but the fields produced by the random electron motions cancel one another; thus no directed electrical current flows under these circumstances. You will remember that a negative charge is attracted to a positive charge, and vice versa. If one end of a conductor is made to become positively charged and the other end to become negatively charged, an electrical force will exist between the two ends of the conductive medium. Electrons will then be driven through the conductor from the negative end to the positive end as long as the force is applied. There is such a force available; it is called by a variety of names, such as *difference in potential, potential difference, electromotive force, voltage*, and *voltage drop*.

13-79. The *difference of potential* or *voltage* can be obtained from a chemical reaction, as in a battery cell, or in many types of electrical devices. If a wire is connected across a battery, electrons in the wire will be repelled from the negative battery terminal and attracted to the positive battery terminal. As a result, a movement or flow of electrons through the wire circuit will take place; the motion of each electron is the resultant of its random motion and the motion produced by the applied voltage. In practice, it is customary to use the words *potential* and *voltage* interchangeably.

13-80. The negative sign (−) used in a battery diagram does not mean that the negative plate is actually at a negative potential, but merely that with respect to any reference point in that circuit, it is at a lower potential than the plate marked with the plus (+) sign.

13-81. One thing you must remember is that when a voltage exists only between two given or selected points, it is the electrons that move or flow from point to point in a conductive medium. In more advanced electronic circuits where the electrical currents are continually varying in strength with time, you will be required to mathematically plot the wave shape of this changing amplitude. Similarly, you will also be required to plot the strength of a voltage wave that continually varies in amplitude with time. The two graphs may or may not exactly coincide, but the graphs are strikingly similar. You can fall into the error of considering a voltage as something that flows simply by comparison of the two types of graphs.

13-82. Whenever two points of unequal charge are connected, a current flows from the more negative to the more positive charge. The greater the EMF or voltage between the charges, the greater the amount of current flow. Electrical equipment is designed to operate with a certain amount of current flow, and when this amount is exceeded the equipment may be damaged. Four common sources of EMF are mechanical (generator), chemical (battery), photoelectric (light), and thermal (heat).

13-83. You will usually use only mechanical and chemical action, with mechanical being the most common. All of the electric power used, except for emergency and portable equipment, *originally* comes from a generator in a power plant. The next discussion will cover magnetism and generation.

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14. Magnetism and Generation

14-1. An understanding of the nature and principles of magnetism is extremely helpful in understanding electrical circuit operation. Electricity and magnetism work hand in hand whenever an electrical circuit is used to perform a useful task. Although motors, generators, and transformers are usually thought of as electrical devices, magnetism plays a vital part in their operation. Since magnetism has a practical application in many different kinds of electrical devices, we will begin with a brief review of the basic laws of magnetism.

14-2. **Basic Laws of Magnetism.** Whenever a bar magnet is dipped into iron filings, a large number of filings cling to the magnet near its ends, but a few attach themselves to the magnet near its center. This action indicates that the magnetism is concentrated at the ends of the magnet. These ends are called the *poles* of the magnet, and the magnetic strength of each of the two poles of a magnet is always equal.

14-3. A magnet that is free to rotate always turns to a north-south direction, aligning itself with the earth's magnetic field. The north-seeking end of the magnet is called the north pole, and the south-seeking end of the magnet is called the south pole. If you bring the south pole of one magnet near the north pole of another magnet there is an attraction between the two poles. If you bring two north poles or two south poles together, there is a force of repulsion between the two poles. This action may be summed up by these two basic laws of magnetism: (1) *Unlike poles attract each other,* and (2) *like poles repel each other.*

14-4. The force of reaction (either attraction or repulsion) between the poles of two magnets varies directly as the product of the strength of the poles and inversely as the square of the distance between them.

14-5. The region around a magnet in which its effect can be detected is known as its magnetic field. The most common method used to show a magnetic field is to place a piece of paper over a bar magnet and sprinkle iron filings over the paper. Whenever the paper is tapped lightly, the filings arrange themselves in a definite pattern, which outlines the magnetic field. The magnetic field is spoken of as being composed of lines of force, or flux lines.

14-6. Figure 57, foldout 2, shows magnetic lines of force around a bar magnet. The flux lines (the field) extend about the magnet from the north pole to the south pole externally and from the south pole to the north pole internally. You should also note that the lines of force never cross each other and that they exist in complete, unbroken paths.

14-7. This concludes our review of the basic laws of magnetism. Now let us turn our attention to electromagnetic fields.

14-8. **Electromagnetic Fields.** Many years ago it was discovered that a current-carrying conductor was surrounded by a magnetic field and that lines of force formed around the conductor. This was before it was realized that moving electrons with their associated magnetic fields make up an electric current. The direction of this magnetic field is tangent to a circle about the conductor, and the strength of the field decreases as the distance from the conductor increases.

14-9. There is a direction associated with magnetic fields, both natural and electromagnetic. The direction is the direction toward which the north pole of a test magnetic needle points when it is placed in the field. The direction depends on the direction of electron flow in the conductor. In part A of figure 58, foldout 2, the electrons are moving into the page and the direction of the field around the conductor is counterclockwise. In part B of figure 58, foldout 2, the electrons are moving out of the page and the direction of the field around the conductor is clockwise.

14-10. The direction of the magnetic field around a conductor may be determined by using the left-hand rule. *If you grasp a conductor with your left hand so that your thumb points in the direction of electron flow in the conductor, your fingers will indicate the direction of the magnetic field.*

14-11. *Magnetic field about a loop.* If a straight conductor is bent into a single-turn loop, the lines of force concentrate within the loop. This concentration occurs because all the lines of force enter the loop from one side and leave at the other side of the loop. This picture is similar to the magnetic field around a bar magnet, and like a bar magnet, the loop has magnetic poles.

14-12. *Magnetic field in a solenoid.* If several turns of wire are wound closely together into the form of a coil, the magnetic fields around each turn will have the same direction. When current flows through the coil, the coil is surrounded by a magnetic field. One end of the coil becomes a north pole and the other end becomes a south pole. To determine the polarity of a coil, use the left-hand rule. Grasp the coil with the left hand so that the fingers point in the direction of electron flow. Your thumb will point in the direction of the north pole.

14-13. What happens if a soft-iron core is inserted into the coil? This action concentrates the magnetic field. The increase in the field is not caused by an increase in intensity, but by the

magnetization of the iron core. The field intensity can be changed only by varying the number of turns in the coil or by varying the current flow through the coil.

14-14. So far in this chapter we have discussed electron physics and magnetism. Earlier in the chapter we used the term "electromotive force." Now, let's combine what we have learned and discuss the mechanical generation of an electromotive force.

14-15. **Producing an EMF.** If you think back to the time when you were attending electrical school, you will probably remember the most common methods of producing an EMF were heat, pressure, photoelectric effect, chemical, and magnetic (or mechanical). The most common methods, of course, are chemical and mechanical. As an aircraft electrician, these are the most important to you. For the time being, let us concentrate on the mechanical method of producing an EMF.

14-16. In the section on magnetism, you learned that whenever an electric current moves through a conductor, a magnetic field is set up around the conductor. If a conductor is moved within the magnetic field around a magnet, an electric current is produced within the conductor as it cuts the magnetic lines of force. This process is known as *induction*, and it is the key to understanding how an EMF is mechanically generated. Now, let's turn our attention to the interaction between magnetic fields and conductors placed within these magnetic fields.

14-17. *Force of magnetic fields on conductors.* If you place a current-carrying conductor in a uniform magnetic field (one that possesses the same strength everywhere in the vicinity of the conductor), the conductor will move. The direction of movement is at right angles to the magnetic field. The movement is caused by the interaction of the field about the conductor (due to the electron flow through the conductor) and the magnetic field in which the conductor is placed. Figure 59, foldout 2, shows a current-carrying conductor placed within a uniform magnetic field. The electron flow in the conductor is into the page, as shown by the symbol + at the center of the conductor. The direction of the magnetic lines of force around the conductor, therefore, is counterclockwise.

14-18. Below the conductor in figure 59, foldout 2, the lines of force produced by the conductor are in the same direction as those produced by the north and south poles of the magnet and tend to reinforce them. Above the conductor, the lines of force of the two fields are in opposite directions and tend to counteract each other. The resultant field below the conductor is strong, whereas the resultant field above the conductor is weak. The repelling action between the lines of force causes the conductor to move up toward the weaker field, as shown by the arrow in figure 59, foldout 2.

14-19. The force exerted on the conductor is proportional to the flux density, the amount of current flow in the conductor, and the length of the conductor perpendicular to the magnetic field.

14-20. Whenever two current-carrying conductors are placed near each other, the magnetic fields around the conductors produce a force which reacts on each conductor. Part A of figure 60, foldout 2, shows the fields around two conductors carrying current flow in the same direction (out of the page). The magnetic lines of force around each conductor are in a clockwise direction. Between the two conductors, the lines of force are in opposite directions and tend to counteract each other. This weakens the field between the conductors, and they move *toward* each other. Part B of figure 60, foldout 2, shows two conductors carrying current in opposite directions. The magnetic lines of force around the left-hand conductor are clockwise, while those around the right-hand conductor are counterclockwise. The resultant field between the conductors is strengthened, since the lines of force are in the same direction and the two conductors are forced apart.

14-21. The process of induction has been talked about in the section of electrostatics, and the process was very similar to a magnetic field passing through a conductor. Energy causing the magnetic field to move is transferred to the free electrons in the conductor. Then electrons gather at one end of the conductor, which causes a difference-in-potential with respect to the opposite end of the conductor. Results! *INDUCED EMF.*

14-22. Now that we have an induced EMF, two factors affecting the quantity of EMF are needed if we want to build a generator. The two factors are the strength of the magnetic field and the relative speed between the conductor and the field.

14-23. *The strength of the field.* The stronger the field, the more lines of force are concentrated between the two poles. Remember, a line of force must cut a conductor to induce an EMF; therefore, if the lines of force are more numerous, the induced EMF will be stronger.

14-24. *Time.* As the relative speed between the conductors and the magnetic field increases, the greater the magnitude of the induced EMF. Control of these two factors means control of the induced EMF.

14-25. Another interesting effect of an induced EMF is to oppose the force causing the induction. This effect is known as Lenz's law.

14-26. *Lenz's law*. The direction of the conductor movement, the direction of magnetic lines of force, and the direction that a current caused by an induced EMF will flow are all factors of Lenz's law. The law states, "In all cases, the induced current is in such a direction as to oppose the motion which generates it." (Refer to fig. 61, foldout 2.)

14-27. Applications of the law will be considered in detail within the discussion covering generators, motors, and motor generators. At this point, we are primarily interested in determining the *polarity of an induced EMF* when the direction of movement by the magnet and the direction of lines of force are known.

14-28. To show that the induced voltage is always opposite to the force that produced it, let us examine figure 61, foldout 2. As shown in the figure, a wire coil wound in the form of a solenoid is placed so that its turns are in a horizontal plane. A galvanometer (G) is connected across the coil to complete the circuit and allow current flow when a voltage is induced. When the north pole of a magnet is thrust into the center of the coil, a voltage is induced. The current which results from this voltage flows in the direction indicated by the arrow labeled "i." So far as the external circuit is concerned, the polarity of the induced voltage is as shown; the top lead being positive and the bottom lead being negative. This causes the top end of the coil to appear as a north pole, which opposes the downward direction of the magnet.

14-29. The induced polarity of the coil must be the same as that of the approaching magnetic pole. Otherwise, it would be necessary only to start a magnetic pole into the coil, and when the magnetic field induced an opposite pole in the coil, the magnet would be drawn in, inducing additional EMF without work. This would provide an unlimited source of energy without doing any work, a condition that is contrary to the law of the conservation of energy.

14-30. The importance of Lenz's law will become obvious when applied to the AC generators discussed in the next section.

14-31. **Simple AC Generator.** Figure 62, foldout 3, shows a simple AC generator. As shown in the illustration, the conductor, also called the armature, has been bent into the form of a coil and mounted so that it can be rotated in the magnetic field produced by the pole pieces. The voltage induced in the ~~armature~~ is shown graphically in the lower part of figure 62, foldout 3.

14-32. When the loop is passing through position 1 (fig. 62, foldout 3), no voltage is induced in the loop because at this instant the conductor is moving parallel to the lines of flux and no lines of flux are being linked with the conductor. As the conductor is rotated toward position 2, side A is moving down through the magnetic field and side B is moving up through the same magnetic field. A voltage is induced in each side of the loop but in opposite directions. This corresponds to the graph in figure 62, foldout 3, in which maximum current flows when the conductor rotates 90°. As the conductor continues to rotate toward position 3, you can see that the current drops off to zero when the conductor has rotated 180°. At position 4 (270°), the current has again reached maximum but in the opposite direction from position 2. You can verify this by the left-hand rule.

14-33. In order to make use of the EMF induced in the rotating conductor, the two ends of the loop are connected to two sliprings, as shown in figure 62. Each ring is continuous and is insulated from the shaft and from the other slipring. The brushes are connected to the load and rest against the sliprings. As the coil rotates, the brushes make sliding contact with the sliprings, completing the circuit at all times.

14-34. The amplitude of the induced voltage depends upon the strength of the magnetic field and the speed at which the coil rotates. In figure 62, if the strength of the magnetic field is increased and the speed of rotation is unchanged, the amount of induced EMF increases. Similarly, if the field strength is unchanged but the coil is rotated at a higher speed, more lines are cut per unit time and a greater voltage is induced. Another way of increasing the number of lines cut is to increase the number of conductors.

14-35. This has been a brief review of the principles of operation of an AC generator. Later in this course we will discuss AC generators in great detail. Now let us discuss cycles and frequency.

14-36. **Cycles and Frequency.** In the previous discussion of a simple AC generator, you learned that each time the conductor passed both a north and south pole it traveled 360 electrical degrees (360E°). Thus, during one complete revolution of a two-pole AC generator, the conductor travels 360E°, as well as 360 mechanical degrees (360M°) (Fig. 62, foldout 3). Suppose we add an additional pair of poles. In an AC generator containing four magnetic poles, the conductor travels 360M° and 720E° in one complete revolution.

14-37. Each time that the voltage goes through 360E° it is a *cycle*. When the voltage completes a half-cycle or 180E°, it has gone through one

alternation. The voltage goes through an alternation when the coil passes one magnetic pole. Hence, the number of alternations is always twice the number of cycles.

14-38. The number of complete cycles occurring in 1 second is known as the frequency of the voltage. Frequency is expressed in terms of cycles; specifically, it refers to the number of complete cycles that occur per second. At this time, you may wonder what determines the frequency of a voltage.

14-39. Every time a coil makes a complete revolution in a four-pole generator it passes two pairs of poles and goes through 720E°. Thus, the number of cycles per revolution is equal to the total number of poles divided by 2.

$$\text{Cycles per rotation} = \frac{\text{number of poles}}{2}$$

14-40. The frequency (cycles per second) equals the number of cycles per revolution multiplied by the number of revolutions per second. If the coil in a four-pole AC generator turns at 60 rps (revolutions per second), the frequency is determined in the following manner.

$$\frac{4}{2} \times 60 = 120 \text{ cycles per second}$$

Speed is usually expressed in revolutions per minute (rpm); therefore, it is necessary to divide rpm by 60 to get rps. Then, for an AC generator with P poles and S speed in rpm, the formula for determining frequency is given below.

$$f = \frac{P}{2} \times \frac{S}{60}$$

or

$$f = \frac{PS}{120}$$

where

f = frequency
P = number of poles
S = speed in rpm

14-41. Given any two factors, the third factor may be determined by using the same basic formula in another form, such as given below.

$$P = \frac{120f}{S}$$

or

$$S = \frac{120f}{P}$$

14-42. In our everyday life the electrical power output is standardized at 60 Hz. For aircraft AC power installations, a frequency of 400 Hz has been adopted. We will explain the reason for this later in this course. Next, we need to discuss the values at different points.

14-43. **Values of AC.** At this point, you no doubt realize that the vertical distance of any point from the horizontal axis of the sine wave is the instantaneous voltage. Further, the top of the sine wave is the maximum positive value and the bottom of the sine wave curve is the maximum negative value. Maximum value can also be called the *peak* value. Twice the peak value, or the difference between maximum positive value and the maximum negative value, is called the *peak-to-peak* value.

14-44. *Effective.* The *effective* value of an alternating current or voltage may be explained best by observing the heating effect of current flow. For practical reasons, it is desirable that 1 ampere of alternating current produce the same heating effect as 1 ampere of direct current. Because alternating current does not maintain a contant value, it is obvious that an alternating current having a peak value of 1 ampere will not produce the same continuous heating effect as 1 ampere of direct current. The continuous effective value of the alternating current lies somewhat between zero and the peak value and is always less than the peak value. At first thought, it might seem that the effective value of AC, expressed in amperes, is the average of the instantaneous values of one alternation, but this is not the case. Let's see why it is not.

14-45. The heating effect of a current varies as the square of the current; that is, it is equal to I^2R. The heating effect of AC, therefore, varies as the average of the squares of the instantaneous values of current during one alternation. The heating effect is positive regardless of the direction of current and will be the same for both the positive and negative halves of the cycle.

14-46. To find the effective value of an alternating current, you must find the square root of the average of all the squares of all instantaneous values of current. In other words, you square a number of equally spaced instantaneous values throughout the alternation, add the squares, divide by the number of instantaneous values you used, and then extract the square root of the quotient. This works out to be 0.707. The resultant is known as the root-mean-square (rms) and is mathematically shown as follows:

$$\text{rms} = 0.707 \times \text{peak value}$$

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14-47. With a peak value of 150 volts, for example, the effective value is 0.707 × 150 or approximately 106 volts.

14-48. To convert from rms to peak value, this formula can be transposed as follows:

$$\text{Peak value} = \frac{1}{0.707} \times \text{rms} = 1.414 \times \text{rms}$$

14-49. For example, commercial AC at 115 volts has a peak value of 1.414 × 115 or approximately 163 volts. The peak-to-peak value is 2 × 163 or 326 volts, which is double the peak value. It may be expressed as indicated below.

$$\text{Peak-to-peak value} = 2.828 \times \text{rms value}$$

14-50. *Average*. Another value of AC that you may encounter is the *average* value. As its name implies, the average value is an arithmetical average of all the instantaneous values in a sine wave for one alternation. If the instantaneous values up to 180° are added and then divided by the number of values added, the average value equals 0.637. Since the peak value of the sine curve is 1 and the average value is 0.637, it can be expressed as follows:

$$\text{Average value} = 0.637 \times \text{peak value}$$

14-51. A peak value of 163 volts, for example, has an average value of 163 × 0.637 or approximately 104 volts.

14-52. **Phase.** In AC circuits, the term "phase" is used quite often to denote a time difference between two quantities alternating at the same frequency. This time difference is generally expressed in terms of electrical degrees. A phase relationship may exist between any two different currents or between the voltage and current in the same circuit.

14-53. Earlier in this chapter, we pointed out that when generating an alternating current, a positive voltage peak is reached at 90E°. If, at the same instant of time, another voltage source is producing the same peak voltage in the opposite direction, we have the condition shown in parts A and B of figure 63, foldout 3. From this figure it should be apparent that the voltage curve in part B has reached the 180° position of its cycle at the same instant that the voltage in curve A is at its 0° position. Thus, the two voltages are out of phase by 180°. We can say, then, that "phase" is the number of E° between like peaks of two different sine waves at the same instant of time. If like peaks occur at the same time, even though one has a greater magnitude than the other, they are in phase. A voltage or current leads another voltage or current if its peak occurs a few degrees before the similar peak of the other. The second voltage or current lags because its voltage or current peak occurs a few degrees after the other.

14-54. At this point, it should be noted that no voltage or current can be exactly 180° or more out of phase with the voltage or current of another circuit. When one voltage is 180° out of phase with another, it must reach its positive peak at the same instant that the other voltage reaches its negative peak. Under these conditions, if voltages of equal value are connected to a common circuit they cancel each other out, and the net result is zero. Later in this course, we will go deeper into phase relationships. Our next section will be an introduction to mathematics.

15. Fundamentals of Mathematics

15-1. Do troubleshooting electricians need a mathematical background to understand the analysis and operation of electrical circuits? Yes!

15-2. Why mathematical relationships? Three functions of mathematics are listed below.

- Mathematics is the language that people use to explain phenomenon occurrences.
- Mathematical analyzation develops logical thinking processes.
- Mathematical relationships aid the experimenter in determining predictable results.

15-3. As an electrician, you practice each of the above functions consciously or unconsciously. Stop for a moment; think back to your last troubleshooting problem.

15-4. The first question you probably asked yourself was, "Is the system receiving power?" The word "power" connotates a mathematical expression concerning voltage and current; therefore, you are explaining a physical phenomenon occurrence. After you checked for power, you broke the system into parts and started to analyze the circuit through logical thinking processes. Each time you made a decision, you narrowed the location of trouble to a smaller section of the system. You were predicting that you would find the trouble in that section in relation to voltage, current, and opposition. So, it is very difficult for an electrician to do his job without a mathematical background.

15-5. This section covers a few areas of mathematical relationships as they are applied to circuit analysis. These areas are Pythagorean theorem, trigonometry, and vector analysis.

15-6. **Pythagorean Theorem.** This theorem is a foundation for further study in vector analysis and trigonometry, so it stands to reason that this is the place to start. Pythagorean's theorem was

the first tool used to solve unknown sides of a triangle. Why triangles?

15-7. Triangles are tools used by electricians to explain voltage, current, opposition, and power in an AC circuit. First, we'll review the solving of triangle problems using Pythagorean theorem before applying the triangles to AC circuit analysis.

15-8. The theorem is stated as follows: *The square root of the sum of the squares of the legs (sides) of a right triangle equals the hypotenuse.* Thus, from the right triangle illustrated in figure 64, foldout 3,c (the hypotenuse) is found by the equation given below.

$$C = \sqrt{a^2 + b^2}$$

For example, if you are given a problem of a right triangle where a = 4 and b = 3, and you want to know the length of the hypotenuse, c, you would solve the problem by substituting in the equation.

$$\begin{aligned} c &= \sqrt{a^2 + b^2} \\ &= \sqrt{4^2 + 3^2} \\ &= \sqrt{16 + 9} \\ &= \sqrt{25} \\ &= 5 \end{aligned}$$

15-9. Use the above method to solve for c when a = 7.071 and b = 7.071. In order that you use minimum time in solving the problem a table of square roots is located at the rear of the volume. The correct answer to the problem is 10.

15-10. If you had trouble with the above problem, then try this one before going on. What is c equal to if a = 6 and b = 8? The correct answer is again 10.

15-11. You should now have some idea of the mathematical relationship between the sides of a right triangle. This relationship will be exploited more fully in the next section.

15-12. **Trigonometry.** If changes in either a or b side of the triangle cause a change in c, then a corresponding ratio exists between all three sides. Therefore, the purpose of trigonometry is to solve triangle problems without extracting a square root.

15-13. Trigonometric functions are especially important for electrical calculations involving alternating current (AC). A large percentage of the problems relating to the analysis of AC circuits involves the solution of the right triangle. These electrical problems when reduced to a right triangle can be easily and quickly solved by trigonometric functions. We shall briefly discuss the trigonometric functions of the sine, cosine, and tangent. Let us begin by drawing a radius to point P on the circumference of a circle, as illustrated in figure 65, foldout 3. From point P, you drop a perpendicular to the horizontal axis thereby forming a right triangle. Let Z represent the radius or the hypotenuse. The letter X represents the vertical side, and the letter R represents the horizontal side. The angle between the hypotenuse (radius) and the horizontal side is known as θ (Greek letter theta). It is customary to designate this angle by the Greek letter θ.

15-14. The trigonometric function of the sine, cosine, and tangent of θ in a right triangle can be found by the following rules. The sine of an angle θ in a right triangle is defined as the ratio of the length of the side opposite that angle divided by the length of the hypotenuse. For example, in figure 65, foldout 3, the sine of the angle θ is

$$\text{sine } \theta = \frac{X}{Z}$$

The cosine of an angle θ is defined as the ratio of the length of the side adjacent to that angle divided by the length of the hypotenuse. For example, in figure 65, foldout 3, the cosine of the angle θ is

$$\cos \theta = \frac{R}{Z}$$

The tangent of an angle θ is defined as the ratio of the length of the side opposite that angle divided by the length of the side adjacent to that angle. For example, in figure 65, foldout 3, the tangent of the angle θ is

$$\tan = \frac{X}{R}$$

15-15. In part A of figure 66, foldout 3, the angle θ is small, and the vertical component X is also small. In part B, the angle and the vertical component X have increased. In part C, when the angle θ is 90°, the vertical component touches the circumference at point P. Notice that this perpendicular to the horizontal axis yields a vertical component equal in length to the radius. Such is the case when the sine of θ is 90°.

$$\sin 90^\circ = \frac{X}{Z} = 1$$

This means at 90°, you get the maximum value of the sine of an angle θ, and it will never be

greater than 1. Why? Because the vertical component can never be greater than the radius.

15-16. As the angle θ increases from 90° to 180°, the vertical component decreases from Z to 0 again. (See fig. 66; foldout 3.) At 180°, the radius is lying upon the horizontal axis and there is no vertical component; thus, the sine of 180° is

$$\sin 180° = \frac{X}{Z} = 0$$

15-17. As the angle θ increases from 180°, the radius is drawn from the horizontal axis down to a point on the circumference. When the vertical component lies below the horizontal axis, the sine of an angle is negative. This is true because from 180° the value of sine θ decreases until the sine reaches a maximum negative value of -1 at 270°, and then the sine begins to increase until it finally reaches 0 again at 360°.

15-18. It is usual for the radius that generates the angle, by rotating around the center of the circle, to start from the horizontal axis pointing to the right and rotate in a counterclockwise direction. This counterclockwise direction of rotation is considered positive in both mathematics and electricity, and angles measured from the horizontal axis with positive rotation are considered positive angles. Clockwise rotation of the generating radius is considered negative rotation, and the angles generated are considered negative angles. The generating radius at the end of a positive angle is considered to be ahead of the horizontal axis, and the angle is spoken of as a leading angle. Thus, in a 90° angle, where the generating radius points up, it leads the horizontal axis by 90°. If the generating radius moves to the spot labeled $-45°$, it has generated a lagging angle of 45°, and if it moves to the position labeled $-135°$, it has generated a lagging angle of 135°. It is usual for angles, both leading and lagging, to be 180° or less. Suppose you have the sine of an angle θ representing $-45°$. Where would this be on the circle? The negative angle begins at 360° and is measured back to 180°. That means a $-45°$ will represent the halfway point between 360° and 270°, which is 315°; a $-90°$ will represent the 270° position; and a $-135°$ will represent the 225° position on the circle. Just remember, the negative angle begins at the 360° position and increases clockwise toward the 180°, and 360° can be referred to as a negative angle. In fact, this is done quite frequently when plotting angles θ in AC circuits. It is more convenient to refer to θ as $-45°$ instead of 315°, or as $-90°$ instead of 270°.

15-19. Plotting the sine of an angle θ is illustrated in figure 67, foldout 3. Here you have a circle that is divided into 12 equal parts, therefore, each part represents $\frac{360}{12}$ or 30°; it could be divided into any other number of parts. The 360° circle is divided into 30° divisions on a straight, horizontal line; it also passes through the center of the circle. The distance covered by the 360° on the straight line is usually the same as the distance around the circle. However, it is perfectly correct to make it larger or smaller, if desired. The relation between horizontal and vertical scales is immaterial. A wave is then drawn as in figure 67, foldout 3. Every point has the same height above or below the horizontal line as the corresponding point on the circle. Thus, at 0°, the point on the circle has 0 height above the horizontal axis; at 30°, it has a height exactly 0.5 of the maximum height. At 60°, its height above the horizontal line is 0.866 of the maximum height. *At 90°, it has attained its maximum value.* At 120°, the ratio of its height to the maximum height is again 0.866; at 150°, it is 0.5; and at 180°, it is again zero. At 210°, it is -0.5; at 240°, it is -0.866; at 270°, it is -1.0; at 300°, it is -0.866; at 330°, it is -0.5; and at 360°, it is again zero.

15-20. As previously mentioned, the ratio of the height of the point on the circle (the vertical side of a right triangle) at any angle to its maximum height (the radius or hypotenuse) is known as the sine of an angle θ.

15-21. The curve showing these variations of the circle height as a function of an angle is called a *sine wave curve.* In all phases of the AC electrical circuits, the sine wave curve is important, because the currents and voltages usually vary as sine waves.

15-22. Another curve that may occur under certain conditions in the AC electrical circuits is called the *cosine curve.* In figure 67, foldout 3, you have plotted the sin θ for every 30°, but suppose you have an AC circuit that produces a cosine curve. Figure 68, foldout 3, illustrates a cosine curve. The values for cos θ (cosine theta) are shown for every 30°. These values are plotted in the same manner as were the values for sin θ. Notice that the cosine curve is the same as the sine curve except that it is displaced by 90°.

15-23. Appendix B gives you the value of the sine, the cosine, and the tangent of angles θ ranging from 0° to 90°. To find the value of sin 5°, you would look under the Angles column and locate 5° 00′ (00′ represents the number

of minutes, and there are 60 minutes in each degree). Across from 5°, under the Sines column beneath Nat (natural), is 0.0872. Thus, the sine 5° = 0.0872. The value for sine 8° is 0.1392. The value for cos 8° is 0.9903. The value for sine 60° is 0.8660. This is derived by locating 60° under the Angles column at the extreme right of the table and then looking at the bottom of the table and finding the Sines column. By going up the Sines column on the Nat (natural) side until you reach the number straight across from 60°, you will find the answer 0.8660.

15-24. So far, we have discussed the right triangle trigonometric functions and right triangle, Pythagorean theorem solutions. At this point, it should be safe to assume you can solve right triangle problems. Do you recall the first reason for studying mathematical relationships? That reason is the basis for studying the next area, vector analysis.

15-25. **Vector Analysis.** Let us now turn our attention to the solution of a problem by vectors. Since you were able to completely solve the problem of a right triangle, finding its six parts, by the Pythagorean theorem and the trigonometric functions, you may wonder why bother introducing vectors. Nevertheless, you are going to solve some electrical problems that are easier solved through the use of vectors. You will work out the solution of circuits that would be almost impossible without using vector quantities. To prepare you for these more complex circuits, let us introduce fundamental facts that apply to vector quantities.

- All angles are measured from the horizontal axis which lies to the right of the vertical axis.
- All angles are considered *positive* if they are measured in a *counterclockwise* direction from the horizontal axis.
- All angles are considered *negative* if they are measured in a *clockwise* direction from the horizontal axis.

15-26. Figure 69, foldout 3, illustrates these important facts. The angle θ is positive in part A and negative in part B. Each vector quantity is represented by a *directed line*. The length of the line is scaled so that its length corresponds to the magnitude of the vector quantity. In part A, vector R = 10 and vector L = 10. What is the length (magnitude) of the resultant vector? If you draw a line parallel to vector L as shown in part A, you have a rectangle. By drawing the resultant vector (the dashed diagonal), as shown in part A, you have formed a right triangle. How do you solve a problem involving a right triangle? That's correct, you would use trigonometry. Thus, the magnitude of the resultant vector is, 14.14.

15-27. *Explanation.* Since both legs of the right triangle are equal to 10, the tangent of the angle the resultant vector makes with the horizontal axis is

$$\frac{10}{10} = 1$$

Now look at Appendix B. You will find that the angle the tangent of which is 1 is 45°. Since L is ahead of R, the angle is a leading angle of 45°, and using sine or cosine functions, the length of the resultant vector is

$$\frac{10}{.7071} = 14.14$$

Thus, we have completely described the vector, giving its magnitude and direction.

15-28. In figure 69,B, foldout 3, vector R = 10 and vector C = 10. By forming a right triangle and using trigonometry, the magnitude of the resultant vector is 14.14. This is the same as for the previous example, but vector C is in a different position than was vector L in the previous example. Because the angle θ in figure B represents a clockwise rotation, the angle the vector makes with the horizontal axis is a lagging angle or a negative angle. The angle θ is now $-45°$. Here again, we have completely described the resultant vector by its magnitude and direction. It is important to note that the magnitude is always positive. It is the angle between the positive horizontal axis and the resultant vector that can be positive or negative. Remember that the angle is always measured from the right-hand (positive) horizontal axis.

15-29. *Three vectors:* So far we have mentioned only two vectors representing quantities. Let's go one step further and have three vectors representing quantities at one time and find the resultant of the three. For example, in figure 70, foldout 3, let's have R = 8, L = 7 and C = 3; find the magnitude and direction of the resultant vector. The vector R is along the positive horizontal axis, while L leads R by 90° and C lags R by 90°. This means that L and C are diametrically opposed. When the vectors are in the same straight line but point in opposite directions as do C and L, the resultant vector has a magnitude that is the algebraic sum of the two vectors and a sense in the direction of the larger vector. The magnitude of the resultant is the difference in magnitudes of the two vectors. Thus, the

resultant of C and L lies along L, and has a magnitude of 4. Let us call this vector (C + L) because it is the vector sum of C and L. Now we want the resultant of (C + L) and R. You can see that (C + L) is a 90° leading vector with a magnitude of 4, and R is along the horizontal axis with a magnitude of 8. Drawing the rectangle as you did earlier, you get a right triangle with one leg equal to 4 and the other equal to 8. The magnitude of the resultant and the direction of this vector can be found by looking for the angle whose tangent is

$$\frac{4}{8} = \frac{1}{2} = .5000$$

From Appendix B you find the angle whose tangent is .5 to be approximately 27°. This is above the positive horizontal axis and hence is a leading angle of 27°.

15-30. You could use the sine or cosine table and use the quotient of $\frac{4}{.4540}$ for the resultant or $\frac{8}{.8910}$ for the resultant. In either event, you would have gotten the same answer.

Electrical Circuit Functions

IN TODAY'S AIR Force, the words "electrical circuit function" have taken on a new meaning to the aircraft electrician. For the most part, the day is long gone when all aircraft electrical problems could be resolved with a simple meter.

2. The electrician must have the type of background that allows complete analysis of electrical and electronic systems as well as their components. The discussion in this chapter deals with the analysis of some of the more common circuits with which you will be required to work.

16. Circuit Operation

16-1. Electrical circuits consist of voltage sources and loads connected together by conductors to complete a path for electron flow. Voltage sources, such as batteries and generators, are sources of electrical energy. They provide the force that moves electrons through the circuit. The load opposes the movement of electrons. The load converts electrical energy into chemical, mechanical, and heat energy for the purpose of doing work.

16-2. The opposition to the movement of electrons in any load can be broken down into resistive, capacitive, or inductive components. Although all circuits consists of these three components to some degree, those that are relatively small when compared to another can be ignored. Because each component has its own peculiarities, they will be treated separately in this chapter. However, one fact must remain clear: each component by itself opposes the movement of electrons.

16-3. The initial step in circuit analysis is the determination of voltage, current, and opposition at any point in the circuit and at any instant of time. This can be accomplished only by proper application of Ohm's law, Kirchhoff's voltage law, and Kirchhoff's current law. These three laws are the fundamental tools in all electrical circuit analysis.

16-4. DC resistive circuits will be used to present the basic laws in this chapter. The reason is that the laws were formulated many years ago based on DC resistive circuits; they are the easiest to understand. However, always keep in mind that they are applicable to all type electrical circuits.

16-5. **Ohm's Law.** The relationships of current, voltage, and resistance were first demonstrated by Georg Simon Ohm, a German physicist. Using very poor and deficient apparatus, but the best to be obtained at that time, he performed a series of experiments that completely settled the questions of (a) the way voltage is distributed throughout a circuit and (b) the relationships of voltage, current, and resistance. Ohm's law states that the current in an electric circuit is proportional to the voltage and inversely proportional to the resistance. The consequences of this statement can be expressed by any one of the following equations, using I to denote current, E to denote voltage, and R to denote resistance: $I = \frac{E}{R}$, stating that the current is equal to the voltage divided by the resistance; $R = \frac{E}{I}$, stating that the resistance is equal to the voltage divided by the current; $E = IR$, stating that the voltage is equal to the current times the resistance.

16-6. *Effect of voltage change.* In parts A and B of figure 71, foldout 4, two separate electrical circuits are shown. These circuits are alike in that a 6-ohm resistor and an ammeter are connected to a voltage source. The difference in the two circuits is in the value of the applied voltage, which is obtained from dry cells; each cell furnishes 1.5 volts.

16-7. In part A of the figure, there is only one cell in the circuit; therefore, the voltage applied to the circuit is 1.5 volts. Neglecting the internal resistance of the dry cell, the voltmeter, V, will indicate 1.5 volts. The resistor in the circuit has a value of 6 ohms. By Ohm's law, the circuit current can be calculated as follows:

$$I = \frac{E}{R} = \frac{1.5}{6} = 0.25 \text{ ampere}$$

A quick glance at the ammeter, A, will verify that 0.25 ampere is flowing through the circuit.

16-8. In part B of the figure, two cells are connected in series in the circuit. The voltage as indicated on the voltmeter, V, is now 3 volts, or just double the voltage of one cell. The resistor in the circuit is still 6 ohms. Using Ohm's law to calculate the circuit current, we have the following:

$$I = \frac{E}{R} = \frac{3}{6} = 0.5 \text{ ampere}$$

Viewing the ammeter, A, will verify that 0.5 ampere is flowing through the circuit. Notice that by doubling the applied voltage, the current has also doubled.

16-9. *Effect of resistance change*. In parts A and B of figure 72, foldout 4, two separate electrical circuits are shown. These circuits are alike except that the value of the resistor is different in each part. In part A of the figure, the initial conditions are fixed. The applied voltage is 6 volts, as indicated by the voltmeter, V, and the resistor has a value of 2 ohms. Using Ohm's law, the circuit current is calculated as follows:

$$I = \frac{E}{R} = \frac{6}{2} = 3 \text{ amperes}$$

16-10. In part B of the figure, another 2-ohm resistor is added to the circuit in series with the original resistor, so that the resistance in the circuit is increased to 4 ohms. Since the same voltage is applied, the circuit current becomes

$$I = \frac{E}{R} = \frac{6}{4} = 1.5 \text{ amperes}$$

This value of current can be verified by observation of the ammeter, A. Notice that the current is decreased by 50 percent.

16-11. *Effect of current changes*. Showing the effect of changes in electrical current is more indirect than for voltage and resistance changes. In figure 73, foldout 4, the variable resistor placed in the circuit is used to adjust the current through the circuit to the desired value, as indicated by the ammeter, A.

16-12. The exact current value is unimportant in this part of the explanation. Similarly, the actual voltage of the battery is unspecified because it is only instrumental in obtaining some desired current flow through the circuit.

16-13. In part A of figure 73, foldout 4, the current through the circuit is adjusted to a value of 2 amperes, as indicated by the ammeter, A; the voltage across the resistor then becomes

$$E = IR = 2 \times 2 = 4 \text{ volts}$$

16-14. In part B of the figure, the variable resistor is adjusted so that the ammeter, A, indicates a current of 1 ampere. The voltage across the 2-ohm resistor should be

$$E = IR = 1 \times 2 = 2 \text{ volts}$$

As you can see, the decrease in current produces a decrease in the voltage across the resistor.

16-15. **Kirchhoff's Laws.** Ohm's law is not sufficient for determining currents in complicated circuits. This law alone will not permit you to compute voltages, currents, and resistances in the complex circuits that may be encountered in practical work. The reason is that Ohm's law is a special case denoting more general relations. Methods of treating complicated circuits are based on Kirchhoff's laws. These laws are simple to state, but the methods of applying them are often quite difficult. Briefly stated, the two laws of Kirchhoff are as follows:

a. The algebraic sum of the currents at any junction of conductors is zero.

b. The algebraic sum of the applied voltages and the voltage drops around any closed circuit is zero.

16-16. *First law*. The algebraic sum of the currents at any junction of conductors is zero. This law can be restated as follows: The amount of electrical current entering a junction point must be equal to the amount of current leaving it. This law is actually a consequence of a more general one known as the principle of charge conservation. For example, assume that a current (I_1) of 1 ampere flows toward point A in figure 74. foldout 4, and a current (I_2) of 5 amperes flows away from point A. What is the current (I_3) flowing between points A and B?

Using a minus sign to represent a current flowing into a junction and a plus sign to represent a current flowing away from a junction, current I_1 becomes -1 ampere and current I_2 becomes $+5$ amperes. Since the algebraic sum of the currents must equal zero, an equation can be written as follows:

$$I_1 + I_2 + I_3 = 0$$

Subtracting I_3 from both sides of the equation yields

$$\begin{aligned} I_1 + I_2 + I_3 - I_3 &= 0 - I_3 \\ I_1 + I_2 &= -I_3 \end{aligned}$$

Then multiplying both sides of the equation by a -1 to make $-I_3$ positive yields

$$-I_1 - I_2 = I_3$$

Substituting known values for currents I_1 and I_2 results in

$$\begin{aligned} -(-1) - (+5) &= I_3 \\ +1 - 5 &= I_3 \\ -4 &= I_3 \end{aligned}$$

This shows that -4 amperes is the value of the current flowing between points A and B; the minus sign shows that the 4 amperes is flowing into junction point A. This is really obvious, since 1 ampere is arriving at junction A at the same time that 4 more amperes are arriving at junction A; then both currents join each other to leave junction A as 5 amperes.

16-17. *Second law.* The algebraic sum of the applied voltages and the voltage drops around any closed circuit is zero. In order to understand what this law means, refer to figure 75, foldout 4, and assume that the circuit current is flowing in the direction shown by the solid-line arrow. The starting point is purely arbitrary, since the algebraic sum is zero. Starting at point A and passing through the 100-volt battery, there is a voltage rise of $+100$ volts at point B. Leaving point B. the current must pass through the 10-ohm resistor before it can arrive at point C; since voltage is equal to IR, you can write $-10I$ as the voltage drop across the 10-ohm resistor. Leaving point C, the current must pass through the 5-ohm resistor before it can reach point D; the voltage drop is $-5I$. Leaving point D, the circuit current must travel through the 50-volt battery before it can arrive at point E; in doing so, there is a voltage rise of $+50$ volts. In traversing the circuit from E back to A, there is a negligible voltage drop. Recording all the data for the various circuit points you will obtain the following:

$$\begin{aligned} \text{A to B} &= +100 \text{ volts} \\ \text{B to C} &= -10I \text{ volts} \\ \text{C to D} &= -5I \text{ volts} \\ \text{D to E} &= +50 \text{ volts} \\ \text{E to A} &= 0 \text{ volts} \end{aligned}$$

Since the algebraic sum must equal zero, equate the voltages in the circuit to zero as follows:

$$\begin{aligned} +100 - 10I - 5I + 50 + 0 &= 0 \\ +150 - 15I &= 0 \\ -15I &= -150 \\ 15I &= 150 \\ I &= +10 \text{ amperes} \end{aligned}$$

Now that I is known it can be substituted in the original equation to check the algebraic sum of the voltages as follows:

$$\begin{aligned} +100 - 10 \times 10 - 5 \times 10 + 50 + 0 &= 0 \\ +100 - 100 - 50 + 50 &= 0 \\ 0 &= 0 \end{aligned}$$

Thus, the algebraic sum of the applied voltages and the voltage drops do equal zero, as accounted for by the direction of the solid-line arrow.

16-18. Now suppose that the current direction were assumed to be in the direction indicated by the dotted-line arrow; this direction is opposite that assumed previously. To show that the starting point is arbitrary, suppose you start at point C. The current leaving point C must travel through the 10-ohm resistor to arrive at point B; since it is traveling the circuit from a lower to a higher potential, the voltage drop from point C to B is $+10I$ volts. The current leaving point B must travel through the battery to arrive at point A; the voltage rise at point A will be -100 volts with respect to point B. The voltage drop from points A to E is assumed to be zero volts since the voltage drop along the wire is considered to be negligible in relation to the remaining circuit. The circuit current leaving point E, in order to arrive at point D, must travel through the 50-volt battery; point D will be -50 volts with respect to point E. Leaving point D, the circuit current must travel through the 5-ohm resistor to arrive at point C; which is at a higher potential than point D; the voltage drop from point D to point C is, therefore, $+5I$ volts. Collecting all data, you will obtain the following:

$$\begin{aligned} \text{C to B} &= +10I \text{ volts} \\ \text{B to A} &= -100 \text{ volts} \\ \text{A to E} &= 0 \text{ volts} \\ \text{E to D} &= -50 \text{ volts} \\ \text{D to C} &= +5I \text{ volts} \end{aligned}$$

Equating the applied voltages and the voltage drops to zero, you will obtain the following:

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$$+10I + (-100) + 0 + (-50) + 5I = 0$$
$$10I - 100 + 0 - 50 + 5I = 0$$
$$15I - 150 = 0$$
$$15I = 150$$
$$I = +10 \text{ amperes}$$

Substituting the value of I into the original equation yields

$$+(10 \times 10) + (-100) + 0 + (-50) + (5 \times 10) = 0$$
$$100 - 100 + 0 - 50 + 50 = 0$$
$$0 = 0$$

From these results, the direction of current flow assumed and the starting point in the circuit are immaterial as long as you are consistent in the application of the principles involved.

16-19. There are three basic types of electrical circuits. They are series, parallel, and series parallel circuits. Proper identification of these circuits will simplify circuit analysis. Certain laws applicable to each type circuit have been derived from basic laws which eliminate the necessity of deriving certain equations each time an analysis is attempted.

16-20. Again circuit discussion will be limited to DC resistive circuits. The analysis of AC resistive circuits is essentially the same as for DC resistive circuits.

16-21. **Series Circuit.** In a *series circuit* the same current must pass through each device to complete its path from the negative to the positive terminal of the source. It is the simplest of all circuits but one to which all complicated circuits can be reduced to simplify analysis.

16-22. *Current in a series circuit.* In part B of figure 72, foldout 4, the current flow in the circuit is from the negative terminal of the battery, through ammeter A, resistor R_1, ammeter A_1, resistor R_2, ammeter A_2, and to the positive terminal of the battery. Obviously, there is but one path for the current to follow, and the same current must be indicated by ammeters A, A_1, and A_2. In a series circuit, the current flow is the same at all points in the circuit. Therefore, the circuit current is

$$I = I_T = I_1 = I_2$$

In order to calculate the current in the circuit, you must know the value of the voltage and resistance. Circuit current can then be determined by Ohm's law.

16-23. *Resistance in a series circuit.* In a series circuit, the total resistance in the circuit is the mathematical sum of all the individual resistances in the circuit. In part B of figure 72, foldout 4, there are two resistors, R_1 and R_2, connected in series. If R_T represents the total resistance placed across the battery terminals, it should be obvious that

$$R_T = R_1 + R_2$$

16-24. *Voltage in a series circuit.* Total voltage in a series circuit can be determined by direct application of Kirchhoff's voltage law.

16-25. Before this voltage can be determined it is important to understand what is meant by a rise in voltage, a fall in voltage, and a voltage drop. In part A of figure 76, foldout 5, the closed-circuit battery voltage of 200 volts is applied to the circuit containing the 100-ohm resistor. Ohm's law shows that

$$I = \frac{E}{R} = \frac{200}{100} = 2 \text{ amperes}$$

Also, by Ohm's law, the voltage across the resistor is as follows:

$$E = IR = 2 \times 100 = 200 \text{ volts}$$

This voltage is, of course, the same as the battery voltage, for it is assumed that the resistance of the connecting leads is negligible. It also serves to show that the total applied voltage must be expended across the circuit. The total voltage expended in a complete circuit, including the source, is always zero.

16-26. The negative terminal of the battery in part A of the figure is being used as the reference or zero point for measuring the potentials of all other points in the circuit. Thus, point A is the point of highest potential (200 volts, positive) with respect to the point of lowest potential (zero volts), point B.

16-27. In part B of the same figure, the 100-ohm resistor shown in part A is replaced by four 25-ohm resistors, R_1, R_2, R_3, and R_4, connected in series across the battery. The voltage drop across resistor R_4 is

$$E4 = IR_4 = 2 \times 25 = 50 \text{ volts}$$

If you connect a voltmeter between points E and D, that is, across resistor R_4, you will measure 50 volts positive; this is a rise in voltage from 0 volts up to 50 volts. The voltage drop across resistor R_4 is

$$\begin{aligned} E_4 &= IR_4 \\ &= 2 \times 25 \\ &= 50 \text{ volts} \end{aligned}$$

If you connect a voltmeter between points D and C, you will measure 50 volts positive across resistor R_3. If you connect the voltmeter between points E and C, you will measure 100 volts positive. This is a voltage rise of 100 volts. Consider the fact that E_4 is 50 volts positive with respect to the zero reference point E. The voltage across E_3 is also 50 volts positive, but E_3 *started* at the point that was already 50 volts positive to begin with. In other words, the two voltages have been added together as follows:

$$\begin{aligned} E_4 + E_3 &= IR_4 + IR_3 \\ &= 50 + 50 \\ &= 100 \text{ volts} \end{aligned}$$

16-28. Suppose that the voltage at point A in the figure is measured, and then the voltage at point B is measured, both with respect to point E. Obviously, the voltage at point B is lower than the voltage at point A; thus, there is a fall in potential in this case. Whether there is a rise or a fall in the potential between two points depends entirely on the order in which the measurements are made. For example, it is equally correct to say that there is a voltage rise from B to A with respect to point E, or a voltage fall from A to B with respect to point E.

16-29. The voltage across a portion of a circuit is called the *voltage drop* across that portion of the circuit. Thus, if a voltmeter is successively connected across points A and B, B and C, C and D, and D and E of the figure, it will, in each instance, show a potential difference of 50 volts. Voltage drop is also called *IR drop*. The meaning of IR drop is apparent when you realize that it is a statement of Ohm's law for voltage.

$$E_{EC} = E_4 + E_3$$

The voltage drop across resistor R_2 is

$$\begin{aligned} E_2 &= IR_2 \\ &= 2 \times 25 \\ &= 50 \text{ volts} \end{aligned}$$

Again, if you connect a voltmeter between points C and B, you will obtain an indication of 50 volts positive, and if you connect it between points E and B, you will obtain a voltage indication of 150 volts positive. The 50 volts dropped across resistor R_2 begins at a point that is already 100 volts positive with respect to point E, and ends at a point where the voltage is 150 volts positive with respect to point E. The remaining voltage, 50 volts, is dropped (used to force current through) across resistor R_1, so that the total voltage of the battery is expended across the circuit. In equation form

$$E_T = E_4 + E_3 + E_2 + E_1$$

where E_T is the open-circuit voltage of the battery.

16-30. *Power in a series circuit.* Whenever current flows through any electrical circuit, a certain amount of power is expended in the form of heat. Figure 76, foldout 5, can be used to illustrate how power is distributed in an electrical circuit. In part A of the figure, the power expended in the 100-ohm resistor can be calculated in three ways as follows:

$$\begin{aligned} P &= IE = 2 \text{ amp} \times 200 \text{ volts} = 400 \text{ watts} \\ P &= I^2R = (2 \text{ amp})^2 \times 100 \text{ ohms} = 400 \text{ watts} \\ P &= \frac{E^2}{R} = \frac{(200 \text{ volts})^2}{100 \text{ ohms}} = 400 \text{ watts} \end{aligned}$$

The total power expended in the circuit is 400 watts.

16-31. Refer to part B of the same figure; since $R_1 = R_2 = R_3 = R_4$, it is sufficient to calculate the power expended in only one of these resistors as follows:

$$\begin{aligned} P &= I^2R \\ &= (2)^2 \times 25 = 100 \text{ watts} \end{aligned}$$

One hundred watts is expended in each series resistor, R_1, R_2, R_3, and R_4. The total power expended in a series circuit is the sum of the powers expended in all resistances of the circuit. Thus, the total power expended in the circuit illustrated is 400 watts.

16-32. **Parallel Circuits.** A parallel circuit is a circuit that has more than one path for current flow. This circuit has the same voltage simultaneously applied to each path from the output terminals of the source.

16-33. *Voltage in parallel circuits.* A schematic diagram of a parallel circuit is shown in figure 77, foldout 5. The negative terminal is connected to point B of resistor R_1, and the positive battery terminal is connected to point A of resistor R_1. It is fairly obvious that the full battery voltage is applied across resistor R_1. Resistor R_2 is also connected to the positive terminal of the battery at point A and to the negative battery terminal at point B. The full battery

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voltage, therefore, is applied directly across resistor R_2. The voltage E_1 applied across resistor R_1 must be the same as the voltage E_2 applied across resistor R_2, because both resistors R_1 and R_2 are connected together at point A on one end and point B on the other end; thus,

$$E_1 = E_2$$

Similarly, resistor R_3 is connected directly across the battery terminals, A and B. The voltage E_3 dropped across resistor R_3 is also equal to the applied voltage and is shown as follows:

$$E_1 = E_2 = E_3 = E_T$$

where E_T is the total voltage supplied by the battery. Voltmeters V_1, V_2, and V_3 indicate the same voltage. The conclusion is that in a parallel circuit the same voltage is applied to each resistance in the circuit.

16-34. *Current in parallel circuits.* Do not make the mistake of thinking that resistors R_1, R_2, and R_3 are connected in parallel with the battery. The mere fact that one circuit element is connected across another does not mean that all the circuit elements are in parallel. For example, resistor R_1 in figure 77, foldout 5, is *physically* connected across the battery, but *electrically*, it is a series circuit because the same current flowing through resistor R_1 is also flowing through the battery. In the same figure, resistor R_2 is connected across resistor R_1 in a parallel combination; the parallel combination of R_1 and R_2 are then connected in series across the battery.

16-35. Suppose that a 6-volt battery is used to supply electrical power to the circuit shown in figure 77, foldout 5. Applying Ohm's law to that branch of the circuit containing R_1, current I_1 must leave the negative terminal of the battery, flow through resistor R_1, and return to the positive terminal of the battery. The value of I_1 will be as follows:

$$\begin{aligned} I_1 &= \frac{E}{R_1} \\ &= \frac{6}{3} \\ &= 2 \text{ amp} \end{aligned}$$

Applying Ohm's law to the other two paths in the circuit will yield

$$\begin{aligned} I_2 &= 3 \text{ amp} \\ I_3 &= 3 \text{ amp} \end{aligned}$$

16-36. Therefore, the total circuit current leaving the battery terminal and arriving at point B is as follows:

$$\begin{aligned} I_T &= I_1 + I_2 + I_3 \\ &= 2 + 3 + 3 \\ &= 8 \text{ amperes} \end{aligned}$$

16-37. At junction A, the three currents, $I_1 = 2$ amperes, $I_2 = 3$ amperes, and $I_3 = 3$ amperes, will reconverge so that the total current arriving at the positive battery terminal will be as follows:

$$\begin{aligned} I_T &= I_1 + I_2 + I_3 \\ &= 2 + 3 + 3 \\ &= 8 \text{ amperes} \end{aligned}$$

16-38. Ammeter A will indicate 8 amperes, and ammeters A_1, A_2, and A_3 will indicate 2, 3, and 3 amperes respectively. The conclusion resulting from these observations is that the total current in a parallel circuit is equal to the sum of the currents in the individual circuit branches. The current through any branch may be computed by application of Ohm's law, and depends on the amount of resistance in that branch.

16-39. *Resistance in parallel circuits.* An application of Ohm's law will show the behavior of resistance in a parallel circuit. The applied voltage across a resistance causes a corresponding flow of electrical current through the resistance. Therefore, the total resistance, R_T, of the circuit in figure 77, foldout 5, is calculated by using the total voltage, E_T, and the total current, I_T, as follows:

$$\begin{aligned} R_T &= \frac{E_T}{I_T} \\ &= \frac{6}{8} \\ &= 0.75 \text{ ohm} \end{aligned}$$

Notice that the battery "sees" a total resistance of 0.75 ohm, even though the lowest ohmic value of any one branch resistor is 2 ohms. But do not forget that as far as the battery is concerned, it is delivering electrical energy to a series circuit. Such behavior leads to the conclusion that the equivalent resistance of a parallel circuit is always less than the resistance of any one branch of the parallel circuits. Furthermore, as far as total current and voltage is concerned, the three parallel-connected resistors, R_1, R_2, and R_3 could be replaced with a single equivalent resistor R_{eq} in SERIES with the battery to maintain the same circuit current.

16-40. In many applications, it is highly desirable to evaluate the parallel combination of resistances as an equivalent series circuit. As previously discussed, Ohm's law is satisfactory for calculating the equivalent series resistance R_{eq} when the applied voltage, E, and the total current, I_T, delivered to the parallel circuit are

known. However, it is often necessary to determine R when neither the voltage nor the current is known. Hence, in figure 78, foldout 5, two resistors are shown in the parallel connection isolated from any source of electrical energy to emphasize the fact that only the resistance is necessary to compute equivalent resistance.

16-41. In addition to resistance, a conductor also possesses conductance, which, as you recall from previous discussions, is an indication of the ability of a material to conduct current. Mathematically, conductance is the reciprocal of resistance, and can be calculated with the aid of the following formula:

$$G = \frac{1}{R}$$

Conductances in parallel can be added together to obtain total conductance; therefore, if you assign G_1 as the conductance of the circuit branch containing resistor R_1, and G_2 as the conductance of the circuit branch containing resistor R_2, you will obtain the total conductance, G_T, of the circuit as follows:

$$G_T = G_1 + G_2 = \frac{1}{R_1} + \frac{1}{R_2}$$

Now that the formula for conductance, G_T, of the circuit has been derived, the total resistance, R_T, of the circuit can be obtained by using the relationship as follows:

$$\begin{aligned} R_T &= \frac{1}{G_T} \\ &= \frac{1}{G_1 + G_2} \\ &= \frac{1}{\frac{1}{R_1} + \frac{1}{R_2}} \end{aligned}$$

16-42. The total resistance of the circuit shown in figure 78, foldout 5, is

$$\begin{aligned} R_T &= \frac{1}{\frac{1}{100} + \frac{1}{200}} \\ &= \frac{1}{0.01 + 0.005} \\ &= \frac{1}{0.015} \\ &= 66.6 \text{ ohms} \end{aligned}$$

16-43. Returning to the circuit of figure 77, foldout 5, you recall that the equivalent resistance of that circuit is 0.75 ohm. An application of the principles just discussed results in the following:

$$\begin{aligned} R_T &= \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}} \\ &= \frac{1}{\frac{1}{3} + \frac{1}{2} + \frac{1}{2}} \\ &\doteq \frac{1}{1.3333} \\ &= 0.75 \text{ ohm} \end{aligned}$$

This method of calculating the equivalent series resistance of a parallel circuit is called the *reciprocal resistance method*, and may be used to determine the total resistance of any number of parallel resistances. It is shown in part B of figure 78, foldout 5. Stated as a rule, the equivalent series resistance of a parallel circuit is equal to the reciprocal of the sum of the reciprocals of the individual parallel resistances.

16-44. Observing the equation of the reciprocal method, shown in figure 78, foldout 5, it appears quite clumsy. By performing arithmetical operations, it can be changed into a more convenient form, as developed below.

$$R_T = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2}}$$

The lowest common denominator of the equation's denominator is R_1R_2; hence, clearing the fractions in the denominator yields the following:

$$R_T = \frac{1}{\frac{R_2 + R_1}{R_1 R_2}}$$

Dividing fractions by inverting and multiplying results in the following:

$$\begin{aligned} R_T &= \frac{R_1R_2}{1} \times \frac{1}{R_2 + R_1} \\ &= \frac{R_1 R_2}{R_1 + R_2} \end{aligned}$$

This procedure is called the *product-sum method* and is very convenient for two resistances. If a circuit contains three or more resistances, the method becomes long and tedious. This method, which is shown in part C of figure 78, foldout 5, may be stated in a rule as follows: The equivalent series resistance of a parallel circuit composed of two resistors is equal to the product of the resistances divided by the sum of the resistances.

16-45. The product-sum method can be used to verify the results obtained in previous discussions with respect to figure 77, foldout 5, even though it is more troublesome to apply. The equation is shown below.

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$$R_T = \frac{R_1 R_2 R_3}{R_1 R_2 + R_1 R_3 + R_2 R_3}$$
$$= \frac{3 \times 2 \times 2}{(3 \times 2) + (3 \times 2) + (2 \times 2)}$$
$$= \frac{12}{16}$$
$$= 0.75 \text{ ohm}$$

16-46. If you prefer the product-sum method because it is easier to remember, you can apply it to circuits with more than two parallel resistances by a method of combinations. To do this, first determine the equivalent resistance of any two parallel branches; the result of this calculation can then be used as one of the resistances to combine with any one of the remaining resistances. Continue the process of combining the calculated resistances until all of the resistances have been included in the calculations.

16-47. For example, the circuit of figure 77, foldout 5, may be used to show how this combination is accomplished. First, find the equivalent resistance R_{eq} of resistors R_2 and R_3 as follows:

$$R_{eq} = \frac{R_2 R_3}{R_2 + R_3}$$
$$= \frac{2 \times 2}{2 + 2}$$
$$= \frac{4}{4}$$
$$= 1 \text{ ohm}$$

The total resistance R_T of the circuit can now be calculated as follows:

$$R_T = \frac{R_{eq} R_1}{R_{eq} + R_1}$$
$$= \frac{1 \times 3}{1 + 3}$$
$$= \frac{3}{4}$$
$$= 0.75 \text{ ohm}$$

The calculation of R_{eq} in the first step of this example shows a very interesting relationship in parallel-circuit resistance. The value of resistors R_2 and R_3 was the same; that is, each resistor had a value of 2 ohms. The equivalent resistance of these two resistors is equal to 1 ohm, which is just half the value of either resistor. This, then, is a special case in calculating the equivalent resistance of resistors of equal value. From this example, a rule can be formulated as follows: When resistors of equal value are placed in a parallel circuit, their equivalent resistance is equal to the result of dividing the value of one resistor by the total number of resistors.

16-48. One other relationship between the values of two resistors in parallel can be shown. Suppose that resistor R_1 had a value of 1 ohm and that resistor R_2 had a value of 10 ohms; the ratio of the resistors is 1 to 10. Calculation of the equivalent resistance is as follows:

$$R_T = \frac{R_1 R_2}{R_1 + R_2}$$
$$= \frac{1 \times 10}{1 + 10}$$
$$= \frac{10}{11}$$
$$= 0.90909 \text{ ohm}$$

This is approximately equal to 0.9 ohm. The calculation shows that when any two resistors in the ratio of 1 to 10 are in a parallel circuit, their equivalent resistance is always approximately equal to 90 percent of the value of the lowest ohmic resistance value. If the two resistors had been 10,000 ohms and 100,000 ohms instead of 1 ohm and 10 ohms, the resulting equivalent resistance would have been approximately 9,000 ohms.

16-49. *Power in parallel circuits.* The power expended in a parallel circuit can be calculated quite easily. Using the circuit shown in figure 77, foldout 5, the power dissipation, P_1, of resistor R_1 is shown below.

$$P_1 = I^2R_1$$
$$= (2)^2 \times 3$$
$$= 12 \text{ watts}$$

Similarly, since R_2 and R_3 have equal values of resistance and equal circuit current through them, the power dissipation in each resistor is shown below.

$$P_2 = P_3 = I^2R_2$$
$$= (3)^2 \times 2$$
$$= 18 \text{ watts}$$

16-50. The internal resistance of the battery is unspecified; hence, the power delivered by the battery must be calculated by using a different relationship than $P = I^2R$. The relationship $P = IE$ is suitable, and yields

$$P_T = I_T E_T$$
$$= 8 \times 6$$
$$= 48 \text{ watts}$$

Checking the power distribution in the external circuit with the power provided by the internal circuit of the battery shows that

$$P_T = P_1 + P_2 + P_3$$
$$48 = 12 + 18 + 18$$
$$48 = 48$$

Thus, the power provided by the battery is expended in the external circuit as a function of the resistance in each parallel branch.

16-51. Series-parallel circuits, as the name implies, are combinations of series and parallel circuits. There are no special rules for analyzing this type of circuit; you must systematically apply the rules for both series and parallel circuits as required. As a general rule, however, it is always best to reduce parallel circuits to an equivalent series circuit as a first step in analyzing the overall circuit.

17. Reactance

17-1. At this point, you have reached the end of the straight circuit analysis. You have finished resistance circuits. The next circuits to be studied will contain capacitance and inductance. These terms are not really new to you because you were exposed to them in the 3-level school. Thinking back, you know that circuits with capacitors and inductors gave you trouble in the resident school. Why? We will attempt to answer this question in the discussion to follow.

17-2. **Capacitance.** Electrical devices that are constructed of conductive material and separated by an insulating material are called *capacitors* or *condensers*. The more acceptable of these two terms is *capacitor*. The conductive materials contained in a capacitor are called *plates*, whether or not the materials physically appear as plates. The insulating material between capacitor plates is called the dielectric material, and may be in a solid, liquid, or gaseous state.

17-3. The capacitance of a capacitor is determined by the plate area, the distance between the plates, and the dielectric material. Increasing the plate area or decreasing the distance between the plates increases capacitance or vice-versa. By using a dielectric material that is a better insulator, you will also increase capacitance.

17-4. **Capacitance Values.** The unit of Capacitance is the farad. This unit, however, is too large for practical circuits. A more convenient unit is the microfarad, which is equal to one-millionth of one farad (1×10^{-6} farad).

17-5. In the previous section, you were shown that resistors could be connected together in various ways to produce different results; that is, in series, parallel, and series-parallel circuits. Capacitors are no exception to this rule. Capacitors are manufactured in standard values. Very often, however, nonstandard capacitance values are required for a particular application and these may be obtained by connecting standard values of capacitors in series, parallel, or series-parallel circuits to achieve the exact capacitance values desired.

17-6. **Series Capacitors.** Suppose that two capacitors are connected in series with each other, as shown in figure 79, foldout 5. Plate X of capacitor C_1 and plate Y of capacitor C_2 are joined together; thus, it is quite obvious that both plates will assume the same electrical potential. Both of these capacitor plates could be merged together into a single plate for practical purposes. Consider plate W of C_1 and plate Z of C_2. These two plates will have opposing operating potentials, but more important than this, dielectric A of thickness d is added to dielectric B of thickness d, plus the thickness of plates X and Y. Notice that as the thickness (d) of the dielectric increases, the overall value of the resulting capacitance decreases. The basic equation for total capacitance in a series circuit is shown below.

$$C_T = \frac{C_1 C_2}{C_1 + C_2}$$

This equation can also be resolved into

$$C_T = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2}}$$

Both of these equations bear a striking similarity to the equations used to compute the total circuit resistance value of resistors in parallel. An examination of these equations reveals that other generalizations that are true of resistors connected in parallel are also true of capacitors connected in series: (1) The total capacitance of the combination is less than the capacitance of the smallest individual capacitor used in the circuit. (2) If the capacitors are of equal value, the total capacitance may be obtained by dividing the capacitance of one of the capacitors by the total number of capacitors connected in series.

17-7. **Parallel Capacitors.** Suppose that two capacitors are connected in parallel with each other as shown in figure 80, foldout 5. Capacitor plates W and Y are connected together; thus both plates acquire the same potential when energy is applied. Similarly, capacitor plates X and Z are connected together; these two plates have the same operating potential, equal in amplitude but opposite in polarity with respect to plates W and Y. It should be obvious that the area of plate W is increased by the area of plate Y; the same holds true for the area of plates X and Z. Inspection of the figure shows that connecting capacitors in parallel does not effectively change the thickness of the dielectric material of the equivalent capacitor. Since capacitance is directly proportional to plate area, the equivalent capacitance for the parallel combination should be

$C_T = C_1 + C_2$

17-8. **Capacitive Circuits—Direct Current.** Capacitive circuits in conjunction with resistive and inductive circuit elements constitute the bulk of electrical and electronic circuits. Resistance-capacitance circuits are widely used in all types of applications because of simplicity and economy; these are identified by the term "RC circuit."

17-9. The conditions in effect prior to the time a capacitor is connected into a direct current circuit must always be known for a complete discussion of the subject. There must be no charge stored in the dielectric material, and the capacitor plates must be electrically neutral. To obtain this condition, both capacitor plates must be short-circuited together for a suitable time to permit neutralization of electrical charges. Part A of figure 81, foldout 5, shows a switch with one set of contacts arranged to provide the short circuit function required during the following discussion of time constant. The other set of switch contacts provide operating potentials to the capacitor, as shown in part B of the figure. Part C of the figure shows a charge-versus-time plot of capacitor current and voltage relationships that will be used during the discussion of time constant.

17-10. *Capacitor charging.* During the following discussion, assume a capacitor has a value of 100 μf. Before and during the first instant that switch S is operated (see part B of the figure), the capacitor plates are considered to be completely neutral; there is no difference of potential across the capacitor. As far as existing potentials are concerned, *both* capacitor plates represent one and the same circuit point. This causes the circuit to appear as a short circuit across the battery terminals. After the first instant, a heavy circuit current will move into one capacitor plate, only to be stopped there because of the insulating dielectric material. At the same instant, a different current having the same direction and amplitude will originate at and move from the remaining capacitor plate into the battery terminal. The amplitude of the capacitor current is very large during this brief instant. As yet, there has been no charge acquired by the dielectric material; hence, the capacitor charge is equal to zero. Therefore, the voltage across the capacitor, E_c, is equal to zero volts.

17-11. After an interval of time, electrons will arrive at one capacitor plate and cause a net negative charge on that plate; electrons that move into the battery cause the remaining capacitor plate to acquire a net positive charge. Since these charges are held capacitively in their respective locations, an electrical force is exerted across the dielectric material. The molecules in the dielectric material establish equilibrium by turning to align themselves with the existing electric field present at the capacitor plates. This movement of dielectric molecules partially neutralizes the charge on the capacitor plates and permits an additional charge to move into the plates. A very definite time interval is required to move electrons into the capacitor and to perform the work required to orient the dielectric molecules with the electric field. Assume that the charge, Q, acquired by the capacitor during one time interval is 18×10^{-5} coulombs; the voltage, E_c, across the capacitor would be .555V.

17-12. Inspection of the graph shown in figure 81, foldout 5, shows that during the first time interval the capacitor current decreases from maximum to 18×10^{-5} coulombs, and the capacitor voltage increases from zero to 0.555 volt. Suppose that another time interval (equal to the first time interval) is chosen, and the charge on the capacitor is recorded at that time. Assume that the charge is now 7.65×10^{-5} coulombs, the voltage, E_c, across the capacitor is now 1.3V. From these two examples, you can see that during the first time interval of the charging cycle of the capacitor, the charging current decreases from some maximum value to 18×10^{-5} coulombs, and then, during the second time interval to 7.65×10^{-5} coulombs. Therefore, the charging current decreases nonlinearly with time. The voltage relationships show that the voltage increases from zero to 0.55 volt and then to 1.3 volts. The current through the capacitor decreases in the same proportion during the same time intervals. A point will be reached when the voltage across the capacitor is practically equal to the applied voltage, and at this point, the charging current will be practically zero.

17-13. *Capacitor discharging.* To observe the conditions during capacitor discharge, switch S must be operated to the position shown in part A of figure 81, foldout 5. This places a short circuit across the capacitor. Capacitor current will be very high during the initial instant, but will then decrease to zero. The stored voltage will also be reduced to zero. This initial change in circuit conditions results from neutralization of mobile charges, that is, the combination of electrons with positive ions. The warped electron orbits of dielectric atoms will now attempt to regain their original orbital positions, but they cannot do so instantaneously. The dielectric atoms will repel electrons out of the capacitor plate, as shown in figure 81, and attract them to the remaining plate to reduce the electrical force

external to the plate. The decay of capacitor charge will be accomplished at the same rate as that shown during the charging process, because the same dielectric atoms are affected in both cases. However, the current and voltage decrease together through a discharging capacitor, as opposed to the voltage increase and current decrease in a charging capacitor.

17-14. *RC time constant*. When a resistor is connected in series with the capacitor, as shown in figure 82, foldout 5, the circuit action is modified in degree but not in kind. Since the two capacitor plates are assumed to have no original accumulated charge, the instant that switch S is operated to the contacts opposite those shown in figure 82, the capacitor plates will still appear to the energy source as a complete and continuous circuit as before. Under these circumstances, full output voltage will appear across resistor R because the total circuit current flowing from the battery will be limited only by the resistance of resistor R. In turn, this means that the capacitor current will not be infinite during this initial period but will be limited to some value by the action of the resistor. On the other hand, the voltage across the capacitor will be zero during the initial period because the atoms in the dielectric material cannot align themselves with the electric field instantaneously; thus, the capacitor appears as a short circuit.

17-15. During any subsequent period, the voltage across resistor R and the voltage across capacitor C must always equal the applied voltage. As the capacitor charges, the voltage across the capacitor increases toward the applied voltage. This means that the voltage across the resistor decreases by the same amount. As the voltage across the resistor decreases, it causes the current through the resistor to decrease also. From this information you may conclude that the capacitor-charging current is still governed by the resistor during any subsequent capacitor-charging period. The amount of time required for a capacitor to reach full charge is dependent upon the value of the resistor relative to the value of the capacitor. With a capacitor of given value, it can hold a very definite maximum charge and no more. If the value of a resistor is increased, the charging current of the capacitor is decreased. With a decreased charging current, a longer time is required for the capacitor to acquire its maximum charge than would be the case without the resistor in the circuit. Since the maximum charge is determined by the value of capacitor C and the charging current of the capacitor is limited by resistor R, it should be apparent that the product of the resistor and capacitor together will determine how long electrical current must flow in order to impart maximum charge to the capacitor. The product of the values of resistance and capacitance is called the *RC time constant* of the circuit; its symbol is T, and it is expressed in terms of seconds. Thus,

$$T = RC$$

where T is expressed in seconds, R is expressed in ohms, and C is expressed in farads.

17-16. When a resistor and a capacitor are connected together in a parallel combination, the circuit action changes somewhat, but the time constant, $T = RC$, remains unchanged. However, a parallel resistance provides a direct electrical path from the negative plate of the capacitor to its positive plate. Should a change in charge occur suddenly at one plate, a current would be sent around the capacitor and through the resistor to restore the conditions to normalcy. Effectively, a series circuit still exists; thus, the statement that $T = RC$ holds true for parallel as well as series circuits.

17-17. The time constant of a circuit is a measure of how rapidly the voltages and currents in a resistance-capacitance circuit can respond to changes in voltage or current amplitudes. A small time constant indicates that the circuit can respond to changes in circuit conditions very rapidly. A large time constant indicates that the circuit responds very slowly to circuit conditions. Therefore, the slope of the charge-discharge curve can be made to conform with almost any desired angle.

17-18. **Capacitive Circuits—Alternating Current.** To reiterate, in a direct-current circuit, if an electromotive force is applied directly across the terminals of a capacitor, the capacitor will tend to react as a constant voltage device. The voltage across the capacitor is zero when the time is equal to zero seconds. At this very same instant the capacitor begins to charge in reaction to the applied electromotive force, and the charging current is at its maximum value. Thus, a counter electromotive force is acquired by the capacitor, and it equals the applied voltage at the end of the designated charge period. Capacitors employed in alternating current circuits react in exactly the same manner.

17-19. From Kirchhoff's laws, the algebraic sum of the voltages around any closed circuit, including the source, is zero. Thus, when the applied electromotive force is zero, the counter electromotive force is also zero. When the applied electromotive force is at a maximum, the counter electromotive force is also at its maximum. Therefore, this voltage, as the term *counter electromotive force* implies, is in opposition to the

applied voltage; this fact gives rise to the expression that the capacitor voltage charge is 180° out of phase with the applied voltage.

17-20. As you can observe from figure 83, foldout 5, the phase of the circuit current can be taken with respect to either the applied voltage or the counter voltage. By standard convention, the phase relationship of current and voltage is predicated on the applied voltage. Hence, the capacitor current leads the applied voltage. As the applied voltage passes through zero, moving in a positive direction, the slope of its curve is positive; at the same time the capacitor current passes through a positive maximum, showing that the capacitor current is displaced in time by 90 electrical degrees. The phase relationship in a pure capacitor is such that the capacitor current leads the applied voltage by 90°.

17-21. *Capacitive phase angle.* As noted in the detailed discussion of series circuits, the current in a series circuit is everywhere the same and provides a reference point for calculation of circuit constants. When an applied voltage, E, is connected to the circuit shown in part A of figure 84, foldout 5, the circuit current, i, will be 90° out of phase with the applied voltage. The voltage, e_R, across the resistance will be in phase with current i. The voltage across the capacitor will be 90° out of phase with respect to the same current, i. The capacitor voltage, e_C, is out of phase with the resistor voltage, e_R, by 90°; refer to part B of the figure.

17-22. The relationship between the applied voltage, the voltage drops, and the phase angle of any series RC circuit may be determined by means of elementary vectors. Since the voltage across the resistor, e_R, is in phase with the circuit current, i, e_R is taken as the reference vector. The reference vector is drawn horizontally to the right; the length of the vector is used to represent the number of volts, e_R. The capacitor voltage, e_C, is out of phase with the voltage across the resistor by 90°. The capacitive voltage vector is always drawn at right angles to the reference vector in a downward direction; the length of the vector is used to represent the number of volts, e_C. If dotted lines are extended from the tips of vectors e_C and e_R to form a completed rectangle, the parallelogram of forces law can be used to provide two important relationships. Refer to part A of figure 85, foldout 5.

17-23. When a diagonal line is constructed through the junction of voltages E_R and E_C you will discover that the length of the resultant vector forms the hypotenuse of a right triangle and is numerically equal to the value of the applied voltage. In other words, when the voltages E_C and E_R are known, the applied voltage can be calculated by using the relationship

$$E = \sqrt{E_R^2 + E_C^2}$$

This is the first of two important relationships to be derived from the parallelogram method in the addition of forces.

17-24. The second relationship to be discussed is the determination of the phase angle. The phase angle can be computed very simply by trigonometric methods. Recalling that the tangent of any angle is the opposite side divided by the adjacent side, you will obtain the relationship

$$\tan \theta = \frac{\text{opposite side}}{\text{adjacent side}}$$

Since it is known that the voltage across the resistor is in phase with the current through the resistor, the direction of the voltage vector, E_R, is the same as the current vector, i. The phase angle, θ, is the angle that the applied voltage, E, makes with the resistor voltage vector, E_R, as shown in part A of figure 85, foldout 5. Substituting the voltage relationships for the more general mathematical relationships, the tangent of the angle resolves into

$$\tan \theta = \frac{\text{capacitive voltage}}{\text{resistive voltage}} = \frac{E_C}{E_R}$$

17-25. The actual phase angle is the angle whose tangent is equal to $\frac{E_C}{E_R}$. This can be shown in equation form by

$$\theta = \text{arc tan } \frac{E_C}{E_R}$$

where θ is equal to the actual phase angle and arc tan $\frac{E_C}{E_R}$ is the angle whose tangent is $\frac{E_C}{E_R}$.

17-26. In consequence of this relationship, if the voltage, E_R, across the resistor is large with respect to the voltage, E_C, across the capacitor, the resultant phase angle will be small. Similarly, if the voltage, E_R, across the resistance is small with respect to the voltage, E_C, across the capacitor, the resultant phase angle will be large. Hence, the value of the resistor in a series RC circuit can cause the circuit current to lead the applied voltage by some angle less than 90°.

17-27. *Capacitive reactance.* A new term had to be developed to distinguish between the opposition offered by a resistor and the opposition offered by a capacitor. Since the reaction of a

capacitor to an alternating voltage is a function of frequency, the word *reactance* was chosen. It is designated by the letter X, and expressed in ohms. *Capacitive reactance* is the opposition offered by a purely capacitive circuit to the flow of alternating current; it is expressed in ohms. It is designated by the relationship

$$X_C = \frac{1}{2\pi fC}$$

that may be properly used only in the special case of sinusoidal waveforms. If the applied voltages and currents are not alternating and sinusoidal in nature, the capacitive reactance equation is not valid and should not be used.

17-28. *Impedance.* When capacitances and resistances are combined together to form a circuit, the total opposition to the flow of current offered by the circuit is *not* the simple arithmetical sum of the reactance, X, and resistance, R. The capacitive reactance, X_C, is added to the resistance, R, in a manner that takes into account the phase differences between the various voltages in the circuit. The total opposition to an alternating current is called *impedance* and is assigned the symbol Z. In accordance with the requirements of this new term, Ohm's law now takes the following forms: (a) $E = IZ$, (b) $I = \frac{E}{Z}$, and (c) $Z = \frac{E}{I}$.

17-29. Recall the relationship $E = \sqrt{E_R^2 + E_C^2}$ from the discussion involving phase relationships. The applied voltage, E, can be replaced with the term IZ. The term E_R^2 can be replaced with the term $(IR)^2$ in direct accordance with Ohm's law. Finally, the term E_C^2 can be replaced with a new term, $(IX_C)^2$. These three substitutions can be used to form the following equation:

$$IZ = \sqrt{(IR)^2 + (IX_C)^2}$$
$$IZ = \sqrt{I^2R^2 + I^2X_C^2}$$

Since the current in the series circuit is everywhere the same, I^2 in the term I^2R^2 is the same as I^2 in the term $I^2X_C^2$. Hence, by factoring

$$IZ = \sqrt{I^2(R^2 + X_C^2)}$$
$$= \sqrt{I^2}\sqrt{R^2 + X_C^2}$$
$$= I\sqrt{R^2 + X_C^2}$$
$$\frac{IZ}{I} = \frac{I}{I}\sqrt{R^2 + X_C^2}$$
$$Z = \sqrt{R^2 + X_C^2}$$

Thus, the impedance of a series RC circuit is equal to the square root of the sum of the squares of the resistance and the capacitive reactance.

17-30. The same result may be obtained by means of vectors. The voltage across resistance E_R is equal to IR, and the voltage across capacitor E_C is equal to IX_C. Since each vector represents a product of which circuit current is a common factor, the vectors may be laid off proportional to R and X_C, which are separated by 90°. Refer to figure 86, foldout 5. The resultant vector, Z, is the hypotenuse of a right triangle and its length represents the quantity of the impedance in the circuit as follows:

$$Z = \sqrt{R^2 + X_C^2}$$

17-31. You can also confirm that the angle is the phase angle because the direction of the impedance vector, Z, is the same as that of the applied voltage vector, E. The phase angle can be calculated by means of the relationship shown below.

$$\theta = \arctan \frac{E_C}{E_R}$$

It can also be calculated by using the relationship shown below.

$$\theta = \arccos \frac{R}{Z}$$

The choice of equation to be employed is, of course, dictated by the information available. You may ascertain that if the resistance is large with respect to the capacitive reactance, the circuit tends to act as a purely resistive circuit, and the phase angle approaches zero degrees. If the capacitive reactance is large with respect to the resistance, the circuit tends to act as a purely capacitive circuit, and the phase angle approaches 90°.

17-32. **Parallel RC Circuits.** Figure 87, foldout 6 shows capacitance C and resistance R connected in parallel across an alternator. Since this is a parallel circuit, the voltages across the resistor and capacitor are the same, and are, therefore, in phase with each other. However, the current through the capacitor leads the applied voltage by 90 electrical degrees, and the current through the resistance is in phase with the applied voltage, as shown in part B of the figure. Thus the capacitive current leads the resistive current by 90°, and the resultant current, or line current, is the vector sum of these two currents. In part A of figure 88, foldout 6, the current through the resistance, I_R, is laid off as the horizontal vector, and the current through the capacitance, I_C, is laid off as the vertical vector. The I_C vector is laid off in the positive direction because this cur-

rent leads the resistive current, I_R. This vector is taken as the reference because it is in phase with the applied voltage and represents the direction of the applied voltage. The resultant vector, I_T, represents the total circuit current, and the angle this vector makes with the horizontal vector, I_R, is the phase angle, θ. Thus, the line current is said to lead the applied voltage by the angle θ, since by conventional rotation the I_R vector follows the I_T vector. Refer to part B of the figure. The phase angle is given by the relationship shown below.

$$\theta = \arctan \frac{X_C}{R}$$

This is exactly the same as the relationship for the phase angle in a series circuit.

17-33. The magnitude of the line-current vector, I_T, must always be greater than either I_R or I_C because it is the hypotenuse of a right triangle. In cases where a knowledge of the phase angle is not required, the total circuit current can be computed by means of the formula below.

$$I_T = \sqrt{I_R^2 + I_C^2}$$

As in direct current circuits, the total current in a parallel RC circuit is always greater than the current in any individual branch circuit. By extension, the total impedance of the parallel RC circuit is always less than the impedance of any constituent branch, as inferred by the relationship shown below.

$$Z_T = \frac{Z_1 Z_2}{Z_1 + Z_2}$$

17-34. **Power in Reactive Circuits.** In DC circuit analysis, the amount of power absorbed by a resistor or by the resistance of a circuit is determined easily and simply by means of Joule's law,

$$P = I^2R$$

where all symbols have been previously defined. Since the voltage drop across a resistor, R, is equal to IR, the equation shown above can be resolved into

$$\begin{aligned} P &= IR \times I \\ &= E \cdot I \end{aligned}$$

These equations for determining power in DC circuits are general and can be applied to any DC circuit.

17-35. In AC circuits, the determination of power is a more complicated process. Since both current and voltage vary with time, the product of the instantaneous values of voltage and current, e and i, is also a function of time, and is called the *instantaneous power*, p. If the AC circuit is strictly resistive in nature, the instantaneous values of current and voltage are in phase with each other; hence, the power can be calculated as follows:

$$p = (+i)\,(+e)$$

and

$$p = (-i)\,(-e)$$

The power delivered to the resistive circuit is always positive in sign, which indicates that the energy is dissipated in the resistor in the form of heat and cannot be returned to the source. In figure 89, foldout 6, the plot of power in a resistive circuit shows that the instantaneous power, p, goes through two cycles during the period of one voltage or current cycle.

17-36. *Apparent power.* When an alternating voltage is applied to a purely capacitive circuit element, there is an immediate current flow, but the corresponding capacitor voltage is not totally developed until 90 electrical degrees later. Refer to figure 90, foldout 6. During the first 90°, the current is decreasing in amplitude while the voltage is increasing in amplitude; however, both the current and voltage are positive in sign. The resulting power developed is calculated generally as follows:

$$p = (+i)\,(+e) = +p$$

This relationship shows that electrical power is being drawn from the source to charge the capacitor.

17-37. During the interval from 90° to 180°, the voltage across the capacitor is still positive but decreasing in value. The current, on the other hand, is increasing in amplitude but in the negative direction. The resulting power developed in the circuit, calculated in general terms, is as follows:

$$p = (-i)\,(+e) = -p$$

The designation of negative power indicates that power is being returned to the source during this interval. A little reflection on the subject of capacitive reaction shows that as soon as the voltage across its terminals begins to decrease, the capacitor will discharge into the circuit in an effort to maintain a constant terminal voltage. Therefore, it must be true that during the 90° to

180° interval the capacitor is returning energy to the source which it absorbed during the 0° to 90° interval.

17-38. The area under the positive loops of the power curve is a measure of the power delivered to the load. The area under the negative loops is a measure of the energy returned to the source, without doing any useful work. In a circuit containing a pure capacitance, the area under the positive loops equals the area under the negative loops, so that the net energy delivered to the capacitor by the generator is zero. The power associated with reactive circuit elements is called *reactive power* or *apparent power* (P_a), and is expressed in terms of volt-amperes; mathematically this relationship is shown below.

$$P_a = IE \text{ volt-amperes}$$

In other words, the power that is returned to the circuit by the reactive components in the circuit is known as reactive power.

17-39. *True power*. When an alternating current is applied to a resistance-capacitance circuit, two facts should become apparent to you. First, whatever voltage exists across the resistor will cause a corresponding current through the resistor; therefore, power is converted to heat in the resistor. Secondly, there is a very definite phase angle between current and voltage that is seldom, if ever, exactly 90 electrical degrees. These two factors show that some electrical power will be expended in an RC circuit by the resistor as $+P$, and some electrical power will be returned to the source by the capacitor as $-P$. The power associated with a resistive circuit element is called the *true power* or *real power* and represents the actual rate of doing work. True power is expressed in watts and may be determined by the following formula:

$$TP = I^2R$$

17-40. *Power factor*. In reactive AC circuits, the relative amounts of apparent power and true power are an important consideration from the point of view of efficiency and circuit design. The ratio of true power to apparent power is called the power factor of the circuit; it is expressed in mathematical terms as follows:

$$\text{Power factor} = \frac{\text{true power}}{\text{apparent power}}$$

$$pf = \frac{P}{P_a}$$

$$= \frac{I^2R}{IE}.$$

17-41. It is important for you to realize that a power factor close to 1.00 (100 percent) is generally to be desired for all reactive AC circuits using appreciable power, since this means that the circuit is very nearly resistive in character. A low percentage power factor figure means that there is a large discrepancy between the values of the voltages and currents in the circuit and the actual values needed to perform the work desired.

17-42. **Inductance.** In the analysis of resistive circuits, any opposition to the flow of electrical current was termed *resistance*. The current in a coil may be compared to an object in motion, such as an automobile, which is retarded by wind resistance and by friction between the tires and the surface of the road. With a constant voltage applied, current through a coil is limited only by the resistance of the coil wire. If, however, the current through a coil is interrupted suddenly, by opening a switch for instance, a considerable spark will jump the contacts of the switch as it opens. Opening the coil circuit is somewhat like suddenly stopping an automobile in motion. From Newton's first law of motion, it is known that an object in motion tends to remain in motion, and a considerable amount of force must be exerted to bring the object to a stop. For instance, if a speeding automobile were stopped suddenly by a stone wall, the momentum that tended to keep the car moving would be expended by demolishing the automobile and generating heat. In the case of the coil circuit being suddenly opened, particularly one carrying heavy current, the apparent momentum of the current meeting the abrupt high resistance of the open circuit produces a high voltage and dissipates itself as heat in the form of a spark.

17-43. Furthermore, Newton's first law of motion states that an object at rest tends to remain at rest unless acted upon by an external force. For example, an automobile must exert considerable force to produce the initial movement of the machine. After the car has reached cruising speed, the only force necessary to keep it moving is the force used to overcome friction. In a like manner, an electric current through a coil cannot be started instantaneously; there is a delay in time between the application of the voltage and the rise of current to its full value. In a coil circuit, electrical current seems to posses inertia as well as momentum.

17-44. *Counter electromotive force*. In the analysis of an induced electromotive force previously considered, you were shown that the magnitude of the EMF induced in a conductor of unit length depends upon the number of flux lines cut per second. Since there is not necessarily any movement of the conductor or of the lines of force in self-inductance, the rate of

change of the flux density is equivalent to physical movement of the conductor. But, as already discussed, the flux density about a conductor is directly proportional to the current in the conductor; the force setting up the flux lines is equal to $0.4\pi nI$. Since 0.4π, or 1.26, is a constant factor, the factor nI is called the ampere-turns. Any change in current changes the ampere-turns factor nI and, consequently, the flux density. Therefore, the magnitude of the self-induced EMF or counter electromotive force depends directly upon the rate of change of the current in the circuit. Thus, a rapidly changing current induces a greater counter EMF than a slowly changing current.

17-45. The EMF self-induced in a conductor-carrying current is a counter electromotive force. This was deduced by Lenz from the principle of the conservation of energy. If the self-induced EMF were not a counter EMF, then an increase in circuit current would aid the applied voltage and would thus tend to increase the circuit current. This process would continue, of course, until the circuit current reached an infinite value—a condition not possible in the physical universe. Lenz's law states that an induced EMF always has such a direction as to oppose the action that produces it. Thus, when a current flowing through a circuit is varying in magnitude, it produces a varying magnetic field which sets up an induced EMF that opposes the current change producing it, namely, a counter electromotive force. In an electrical circuit, the characteristic property of the circuit that tends to prevent a change in the value of the electrical current flowing in it is called *inductance*, and is directly comparable to the inertia of physical objects.

17-46. *The henry.* The magnitude of the counter electromotive force opposes the applied voltage by the product of the inductance of the coil and the change in current with change in time. The greater the CEMF produced in the circuit, the greater the opposition to a change of current in that circuit. Therefore, the CEMF produced by a specified change in circuit current is a measure of the inductance of the circuit, expressed in henrys. A circuit has an inductance of 1 henry when a current change of 1 ampere per second causes a counter electromotive force of 1 volt to be induced in it. Since the henry is defined in practical units, the factor 1×10^{-8} must be used if the CEMF is to be expressed in volts and the rate of change of current in amperes per second.

17-47. **Inductive Circuits.** Inductors, like other circuit elements, can be connected in series, parallel, and series-parallel circuits. However, the circuits, as constructed, do not always perform in accordance with calculations, because of interacting magnetic fields. Since these fields are invisible, it is rather difficult to place inductors, even the shielded types, so that they will not interact. Quite often a mounting space is chosen, and a hole is drilled in the chassis to permit wiring into the circuit; upon completion, the circuit is energized and set into operation. A suitable detecting or indicating device is then connected into the circuit to measure the reaction of the coil. The coil is rotated slowly as the indicator is observed for the desired indication, usually minimum field interaction. The inductor is then held in this position, and the mounting holes are marked. This procedure is followed by the drilling of the chassis, and the permanent mounting of the inductor. As long as the magnetic fields of the various inductors used do not interact with each other, the actual performance of a series, parallel, or series-parallel circuit will approximate its calculated performance.

17-48. *Series inductance.* The total inductance, L_T, of inductors connected in series with each other is the sum of the individual inductances in the circuit, provided their individual magnetic fields do not interact with each other. Mathematically, this relationship is expressed as follows:

$$L_T = L_1 + L_2 + L_3$$

Observe the similarity between this equation and the equation for calculating the total resistance of a series circuit.

17-49. *Parallel inductance.* The total inductance, L_T, of inductors connected in parallel with each other is calculated by using the relationships shown below.

$$L_T = \frac{L_1 L_2}{L_1 + L_2} \text{ or } L_T = \frac{1}{\frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3}}$$

These formulas are based on the assumption that the magnetic fields of the inductors do not interact with each other. The similarities between these equations and the parallel resistance equations should be obvious to you. The generalizations resulting from these equations follow the same pattern as the comparable equations for resistors in parallel circuits.

17-50. **Inductive Circuits—Direct Current.** Inductors are more widely employed in direct-current circuits than are capacitors, chiefly because inductors are used in electromechanical devices such as motors, generators, relays, and automatic recording mechanisms. They are widely used in conjunction with resistors to form a variety of

electrical and electronic circuit functions. Circuits that contain only resistance and inductance are called *LR circuits*.

17-51. *Growth cycle*. Refer to part A of figure 91, foldout 7, which shows the LR circuit shorted by switch S. As long as the switch remains in the position shown, no voltage will be applied to the circuit. Assuming that the switch has been in this position for a long period of time, there will be zero current in the circuit and zero voltage across the LR circuit. Operation of switch S will transfer the LR circuit from the short circuit to the battery and start the inspection interval. Considering only the inductor at this time, you know that the applied electromotive force tends to establish an electrical current through the inductor winding. This same current produces a magnetic field, which in turn induces a counter electromotive force that opposes the action of the applied electromotive force. Since the applied and counter electromotive forces are in opposition, the trend is toward mutual cancellation. Complete cancellation of the applied EMF is never accomplished, however, because the CEMF and the coil current establishing that value of CEMF are both dependent upon the applied EMF. In view of this behavior, the circuit current will remain at zero during the initial closure of the switch. According to the laws applicable to series circuits, the current in one portion of the circuit is always equal to the current in other portions of the same circuit. Since the circuit current is zero during this initial moment, the voltage drop across the resistor must also be zero by application of Ohm's law. The data gained from these observations show that, at the instant the switch is operated, the full value of the applied electromotive force is developed across the inductor winding, the voltage across the resistor remains at zero volts, and the current through the series circuit remains at zero. This data is shown in the graphs of parts B and C of figure 91, foldout 7.

17-52. As the current through the circuit begins to increase with time, a corresponding voltage is developed across the resistor, as shown by the solid line in part C of the figure. The voltage across the inductor winding is decreased by the same amount in conformance with Kirchhoff's laws. The net result is that the voltage across the resistor increases with increasing current, while the voltage across the inductor decreases with increasing current. At some point in time the circuit current will reach its maximum practical value, and the voltage will be distributed in such a manner that all of the applied voltage appears across the resistor and none appears across the inductor.

17-53. When a DC voltage is applied to a pure resistance, the current is said to rise immediately to its maximum value. But if an inductor is placed in a DC circuit, the rise in current through the inductor is retarded by the counter electromotive force. The current rises rapidly at first and then gradually tapers off to its maximum value, as shown in figure 92, foldout 7. An analysis of the curve reveals that it is exponential in nature. Along the horizontal axis of the graph, time is divided into equal incremental units. In the first incremental unit of time, the current through the inductor rises to 63.2 percent of its maximum value; the current must rise an additional 36.8 percent before reaching its maximum value. In the second incremental unit of time, the current through the inductor will rise another 63.2 percent. Thus at the end of the second incremental time period, the current has risen to 63.2 + 23.2 = 86.4 percent of its maximum value. The inductor current will rise 63.2 percent of the remaining distance to the maximum value during each incremental time period. Theoretically, in such a progression, the current would never reach a maximum value because it would always be increasing 63.2 percent of the remaining distance for each succeeding time period; but for practical purposes, the inductor current is considered to have reached a maximum value when five time periods have elapsed.

17-54. *Decay cycle*. Assume that the circuit has been energized for a long period of time so that steady values of currents and voltages are attained, as shown in part A of figure 93, foldout 7. If switch S is now operated, the LR circuit will be transferred from the battery to the short circuit. Several reactions will all occur simultaneously during this instant. First, the applied electromotive force will be removed from the LR circuit, and the circuit current from the battery source will cease. Secondly, the magnetic field established by the inductor will collapse because there is no longer any magnetizing current. The collapsing magnetic field, however, induces a voltage in the inductor winding. This new induced voltage will be a new counter electromotive force induced in such a direction as to maintain the same current amplitude and direction that it previously had. The induced current now becomes circuit current and, as such, flows through resistor R. As a result of this circuit current, a voltage is also present across the resistor; refer to parts B and C of the figure.

17-55. The direct current through the inductor cannot fall immediately to zero as it would in a purely resistive circuit. The self-induction of the

coil operates to maintain a steady current flow. Figure 94, foldout 7, shows a graph representing the manner in which the current decays with time as it flows through the LR circuit. This curve is the inverse of that shown in figure 92; that is, it has the same general shape, but it is decreasing instead of increasing. The LR circuit current decreases 63.2 percent of its remaining value per incremental time period. This process continues for five equal incremental time units. After that, the current is considered to be zero.

17-56. *LR time constant.* The recurring 63.2 percent of maximum rise or fall of inductor current in a fixed unit of time is called the *time constant* of the circuit. The larger the value of inductance, the longer the unit of time necessary for the circuit current to rise to a value that is 63.2 percent of its maximum value. The larger the value of the resistor in the circuit, the smaller the final value of circuit current; hence, a shorter time is required for the same circuit to reach the 63.2-percent point on the curve. On the basis of this information, the LR time constant T, expressed in seconds, is equal to the quotient of the inductance L and the resistance R, expressed in henrys and ohms respectively. This information is stated in a mathematical equation as follows:

$$T = \frac{L}{R} \text{ seconds}$$

17-57. The time constant of a circuit is a measure of how rapidly the voltages and currents in an inductance-resistance circuit can respond to changes in applied voltage or current amplitudes. A small time constant permits the circuit to adjust very rapidly to changes in circuit conditions; whereas, a large time constant causes the circuit to respond more slowly. The slope of the current growth-decay curve can be changed to almost any desired angle.

17-58. **Inductive Circuits—Alternating Current.** Inductors used in alternating-current circuits exhibit the same behavior as they do when placed in direct-current circuits. One of the reasons that they seem to react differently is that the alternating current is continuously changing in amplitude; as a result, the inductor is never permitted sufficient time to exhibit the characteristic exponential behavior observed in direct-current circuits. In part A of figure 95, foldout 7, a sinusoidal voltage is applied to a pure inductance. The current through the inductor also follows the sinusoidal voltage, but as you have already concluded, there is a delayed current-voltage relationship. The delay between voltage and current is called *phase shift.*

17-59. By Kirchhoff's law it is known that the algebraic sum of the voltage drops around any closed circuit is equal to zero. Thus,

$$E_{applied} + E_{CEMF} = 0$$
$$E_{applied} = -E_{CEMF}$$

17-60. *Inductive phase angle.* In any purely resistive circuit, the voltage and current are said to be in phase. Figure 96, foldout 7, shows a resistive circuit and illustrates graphically the in-phase relationship of a sinusoidal voltage and current across the resistance. From the graph, you can see that the current and voltage are alternating together at the same frequency. Current rises as the applied voltage rises and is maximum when the applied voltage is maximum. Current decreases as the voltage decreases and crosses the zero axis at the same time that the voltage crosses that axis.

17-61. In any circuit containing both inductance and resistance, there is a 90° phase shift between the voltage and current across the inductance and no phase shift between the voltage and current across the resistance. But it must be emphasized that in any series circuit, the current is the same at all points. Since the current is the line of reference for both the inductance and the resistance, the voltage across the resistor is in phase with the current through the resistor. The voltage across the inductor is 90° out of phase with the current through the inductor. Therefore, it follows that the voltage across the inductor is 90° out of phase with the voltage across the resistor; refer to part B, figure 97, foldout 7. Thus, the action of an alternating current injected into a series LR circuit results in two separate voltage drops that are 90° out of phase with each other. The resultant sum of these two voltages equals the total voltage drop in the whole circuit, and by Kirchhoff's law is equal to the applied voltage.

17-62. The amount of phase shift of current and voltage in such a circuit is measured, not with relation to the voltage across the inductor alone (always 90°), but with relation to the applied voltage. The applied voltage and the phase angle, θ, of any LR circuit may be determined by means of vectors. In part A, figure 98, foldout 7, the voltage across the resistance is laid off along the horizontal vector and the voltage across the inductance along the vertical vector. Since these two voltages are 90° out of phase, the phase angle between them is a right angle. By completing the parallelogram, indicated by the dotted lines in part A of the figure, you can see the resultant vector, E, is the hypotenuse of a right triangle. Then by the Pythagorean theorem

$$E^2 = E_R^2 + E_L^2$$
$$E = \sqrt{E_R^2 + E_L^2}$$

This is the first of two important relationships to be derived from the parallelogram of forces laws.

17-63. From the previous discussion, the circuit current is known to be in phase with the voltage across the resistance; therefore, the position of the current with relation to the applied voltage is the same as vector E_R, the voltage across the resistance. The phase angle, θ, is the angle that the applied voltage vector, E, makes with vector E_R, as shown in part A of the figure. The angle θ may be measured in terms of any of its trigonometric functions depending on the values known; however, the most useful and convenient is the tangent. Substituting the voltage relationships for the more general mathematical relationships, the tangent of the angle resolves into

$$\tan \theta = \frac{\text{inductive voltage}}{\text{resistive voltage}} = \frac{E_L}{E_R}$$

17-64. Therefore, if the voltage across the resistance is large with respect to that across the inductor, the resultant vector will approach the horizontal vector, and the phase angle will be small. In a like manner, if the voltage across the resistor is small with respect to the voltage across the inductor, the resultant vector will approach the vertical. In this case, the phase angle will approach 90°. Hence, the presence of resistance in an inductive circuit causes the current to lag the applied voltage by some angle less than 90°.

17-65. *Inductive reactance, X_L.* The opposition offered to a specific change of current by an inductance is measured during any given instant in terms of the counter EMF, the voltage that opposes the applied EMF. In DC circuits, however, any opposition to current flow is termed *resistance* and is measured in ohms. In AC circuits, it is also convenient to measure inductive opposition in terms of ohms rather than in terms of volts or counter EMF. This type of alternating-current opposition is called *inductive reactance*, and is assigned the symbol X_L to distinguish it from the opposition due to a resistance.

17-66. The Inductive reactance equation

$$X_L = 2\pi fL$$

specifies that the inductive reactance of an inductor is equal to the angular velocity of the sinusoidal waveform times the inductance of the inductor. Take special notice of the term *sinusoidal* in the previous statement; this equation is valid if, and only if, the driving source is a sine wave in nature. If the AC waveform is not sinusoidal, this equation cannot be employed.

17-67. *Impedance.* In any series circuit containing both inductance and resistance, the total opposition offered by the circuit is not the simple arithmetic sum of the inductive reactance, X_L, and the resistance, R. The inductive reactance must be added to the resistance in a manner that takes into account the degree of phase difference between the two voltages in the circuit. The applied voltage, E_T, can be calculated from the knowledge of the component voltages E_L across the inductance and E_R across the resistor, using the relationship below.

$$E_T = \sqrt{E_L^2 + E_R^2}$$

These voltages can be calculated on the basis of IX_L for the inductor and IR for the resistor; direct substitutions of these quantities in the previous equation yields

$$E_T = \sqrt{(IX_L)^2 + (IR)^2}$$

Expansion and factoring produce the following equations:

$$\begin{aligned} E_T &= \sqrt{I^2X_L^2 + I^2R^2} \\ &= \sqrt{I^2(X_L^2 + R^2)} \\ &= \sqrt{I^2}\sqrt{R^2 + X_L^2} \\ &= I\sqrt{R^2 + X_L^2} \end{aligned}$$

The opposition which the circuit offers to the flow of electrical current is the ratio of the voltage, E_T, to the circuit current, I.

$$\frac{E_T}{I} = \sqrt{R^2 + X_L^2}$$

The symbol used to denote the total opposition of a circuit to the flow of alternating current is the impedance symbol, Z; by substitution, this yields

$$Z = \sqrt{R^2 + X_L^2}$$

Thus, the impedance of a series LR circuit in alternating-current circuit applications is equal to the square root of the sum of the squares of the resistance and the inductive reactance.

17-68. The same result may be obtained more readily by means of vectors. The voltage across the resistance, E_R, is equal to IR, and the voltage across the inductor, E_L, is equal to IX_L. Since each vector represents a product of which current is a common factor, the vectors may be laid off proportional to R and X_L and separated

by 90° as shown in figure 99, foldout 7. The resultant vector, Z, is the hypotenuse of a right triangle, and it represents the impedance of the circuit, given by the relationship $Z = \sqrt{R^2 + X_L^2}$. Vector representation also provides information relative to the phase angle. Usually, the phase angle of the circuit is calculated on the basis of the tangent or cosine of the angle because this is usually the type of information available from the circuit itself; however, there is no reason why other trigonometric functions cannot be used just as appropriately.

17-69. **Parallel LR Circuits.** Part A, figure 100, foldout 7, shows an inductance, L, and a resistance, R, connected in parallel across an AC source. In a circuit of this type, the voltage across the inductance is equal to the voltage across the resistance, and this voltage is the same as the applied voltage. Therefore, all voltages in this circuit are in phase with each other. However, the current through the inductance lags the applied voltage by 90°, and the current through the resistance is in phase with the applied voltage. Refer to part B of the figure. Thus, the current in the inductance lags the current in the resistance by 90°. The resultant current, or line current, is the vector sum of these two currents.

17-70. In part C of figure 100, foldout 7, the current through the resistance, I_R, is laid off as the horizontal vector. The I_L vector is laid off in the negative direction because this current lags the current in the resistance. The I_R vector is taken as the reference vector, because it is in phase with the applied voltage, which is common to both branches of the circuit. Now, as in any circuit, the current in the resistor is equal to the voltage across the resistor divided by the resistance.

$$I_R = \frac{E}{R}$$

The current in the inductor is equal to the voltage across the inductor divided by the inductive reactance, X_L. It can be stated mathematically as

$$I_L = \frac{E}{X_L}$$

17-71. The resultant vector, I_T, represents the total current in the circuit, and the angle this vector makes with the horizontal is the phase angle, θ. The angle θ is the angle that the line current makes with relation to the applied voltage, since, as shown in part C of figure 100, foldout 7, the direction of the applied voltage is the same as that of the vector I_R. By convention, vectors are rotated in a counterclockwise direction; since the I_T vector follows the E vector, the line current is said to lag the applied voltage by the angle θ.

17-72. In the analysis of parallel LR circuits, the reference vector is usually the applied voltage vector instead of the current vector. The reason for this is that the voltage across the parallel circuit is the same across all branches.

17-73. **Power in Reactive Circuits.** Power in reactive circuits has already been discussed in the previous section, that is, true power versus apparent power and power factor. The principles discussed are equally valid for inductive circuits with the exceptions that are to be discussed in the following few paragraphs.

17-74. When an alternating voltage is applied to a purely inductive circuit element, the circuit voltage is developed across the coil immediately upon application of the source energy; however, the corresponding coil current is not developed until 90 electrical degrees later. Reference to part B of figure 101, foldout 7, will show that during the first 90°, the voltage is increasing and is positive in sign, +e, while the current is decreasing and is negative in sign, −i. The resulting power developed can be calculated on the following basis.

$$\text{Power} = (-i)(+e) = -p$$

Accordingly, power is being returned to the source as indicated by the negative sign. During the next 90° interval, the voltage is decreasing in value, but it is still positive in sign. The current is increasing in value, and its sign is positive. Following the same procedure as before, the calculation yields

$$\text{Power} = (+i)(+e) = +p$$

The result indicates that power is being absorbed from the source. Thus, the inductive power curve has both positive and negative loops. Comparison of the capacitive power curve with the inductive power curve shows that the two curves are opposed to each other.

17-75. **LCR and Resonant Circuits.** In previous sections of this chapter, the fundamental properties of resistive, capacitive, and inductive circuits were discussed to show their behavior (a) as pure circuit elements and (b) as circuit elements in combination with a resistance. A knowledge of the principles of these circuit elements is especially important to an understanding of this section; therefore, it is important for you to review these principles before attempting to understand this portion of the text.

17-76. The four basic relationships between voltage and current are itemized as follows:

a. The current flowing through a resistance is in phase with the applied voltage.

b. The current flowing through an inductance or a capacitance is out of phase with the applied voltage.

c. The current flowing through an inductance lags the applied voltage by 90°.

d. The current flowing through a capacitance leads the applied voltage by 90°.

17-77. *LCR circuits.* All circuit elements possess some distributed characteristics. For example, a resistor never contains pure resistance without some traces of inductance and capacitance. The discussion of inductance and inductive circuits definitely indicated that a certain amount of resistance and capacitance are unavoidably present in an inductor. By the same token, a certain amount of resistance and inductance is present in a capacitor. Therefore, circuit elements are never pure entities in themselves; they always contain their primary or lumped characteristic, which dominates the circuit, and small distributed characteristics in trace amounts. Depending upon the nature of a particular circuit and its application, the distributed characteristics are accounted for in a circuit by including the symbol of the distributed element as a lumped constant within the equivalent circuit. An inductor, for example, contains distributed capacitance and resistance. The resistance is present, no matter what frequency is applied; hence, you must account for the resistance of the coil by including an imaginary lumped resistance in series with the inductor winding for calculation purposes. The frequency of the input voltage or current determines the importance of the distributed capacitance of the coil; for higher frequencies, this factor cannot be ignored. Distributed capacitance can be accounted for by placing a capacitor in series with the coil. The capacitance value must be equal to the distributed capacitance of the coil.

17-78. From your studies of the two previous sections, you should recall that an inductor causes the circuit current to lag the applied voltage, while a capacitor causes the current to lead the applied voltage. It is reasonable to expect that an interchange of electrical forces will cause a certain amount of cancellation between leading and lagging currents and thereby produce no predominant characteristic. This characteristic will be either leading or lagging, depending upon the relative values of the inductor with respect to both the capacitor and the frequency of the source voltage. Assuming that a capacitor and an inductor are present in a given circuit and assuming that the reactance of the capacitor is smaller than the reactance of the inductor, the reactance of the capacitor will cancel an equal amount of inductive reactance. This leaves the remaining inductive reactance in control of the circuit current. In a series circuit, the current is always governed by the circuit element that has the largest impedance.

17-79. When you are analyzing LCR circuits, remember that resistances can only be directly added to or subtracted from resistances; likewise, reactances can only be directly added to or subtracted from reactances. At no time can resistance and reactance be added together without taking the phase angle into consideration; hence, reactance and resistance can be added together only in quadrature. In relation to the preceding paragraph, this means that when analysis of LCR circuits is required, the capacitive reactance is always subtracted from any inductive reactance contained in that branch of the circuit. The resulting reactance is then added in quadrature to the resistance of the circuit to obtain the circuit impedance.

17-80. *Resonant circuits.* Suppose that a variable-frequency generator and a suitable indicating device are connected to an LCR circuit, which may be either a series, parallel, or series-parallel circuit. As the frequency of the generator is changed, there will be one frequency that will tend to highly accentuate either the circuit current or the circuit voltage distribution. The circuit, at that single frequency, is termed a *resonant circuit,* and the frequency creating the accentuation of voltage or current is called the *resonant frequency.* Both conditions must exist simultaneously for resonance to occur; that is, no circuit can be considered resonant unless the resonant frequency is applied to the circuit. The frequency of the generator is never the resonant frequency unless it is applied to a circuit that is resonant at that frequency. If any other frequency is applied to the circuit, the circuit will not exhibit resonant-frequency characteristics. If the circuit is energized by the resonant frequency, and if any of the reactive circuit elements is changed, the circuit will no longer be resonant, and the generator frequency will no longer be the resonant frequency of the circuit.

17-81. *Conditions for resonance.* The reactive circuit elements are responsible for the condition

known as *resonance*. Resonance occurs at the frequency that causes the inductive reactance of the circuit to be exactly equal to the capacitive reactance of the circuit; mathematically

$$X_L = X_C$$

This relationship indicates that the phenomenon of resonance is unaffected by the type of circuit in which the inductor and capacitor are located, that is, whether in a series, parallel, or series-parallel circuit.

Solid State Control Circuits

IN CHAPTER 6 you studied certain principles and laws pertaining to electrical circuits. In this chapter, these principles will be used to explain the operation of magnetic devices, semiconductors, and related circuitry.

2. The magnetic devices we discuss are magnetic amplifiers and transformers. "Mag amps," the common term for magnetic amplifiers, are covered from the construction and theory of operation point of view; plus, an application of a "mag amp" operating in a simple voltage regulator circuit is shown.

3. Of the many solid-state devices in use today, the aircraft electrician is mainly concerned with crystal diodes and transistors. The discussion will be directed towards basic operation and application of these devices.

18. Magnetic Devices

18-1. For many years, engineers have used magnetic devices in the control and transfer of energy in electrical systems. However, these magnetic devices have usually been large and used only in commercial power production systems. With the advent of AC power systems for aircraft, magnetic devices have been refined and reduced in size and are now used as voltage and frequency control units. Magnetic devices have proven to be more reliable and require less power to operate than voltage and frequency units that use electron tubes. As aircraft electrical systems are improved, more and more magnetic devices will be used.

18-2. Certain fundamentals must be explained before discussing magnetic devices, and we will start with magnetic circuits. Magnetic circuits are comparable to electron circuits; therefore, a good knowledge of electron theory will be a great help toward your understanding magnetic circuits.

18-3. **Magnetic Circuits.** The laws that apply to a magnetic circuit are similar to the laws that apply to an electric circuit. It has been shown previously in this volume that magnetic flux forms closed loops. The path that magnetic flux follows, either through air or through a magnetic material, is called the magnetic circuit.

18-4. In order to produce an electric current, a voltage (electromotive force) is required. Similarly, to produce a magnetic flux, a force known as magnetomotive force (MMF) is required. For a given electromotive force (EMF), the amount of current that flows in an electric circuit depends on the amount of resistance in the circuit. Similarly, in a magnetic circuit, for a given mmf, the amount of flux produced depends on the amount of reluctance in the circuit. It is evident that in both the magnetic circuit and the electric circuit the relationship expressed in this statement is true. *The result produced is directly proportional to the force that produced it and inversely proportional to the opposition encountered.*

18-5. This statement can be expressed for the electric circuit as

$$\text{Current (I)} = \frac{\text{electromotive force (EMF)}}{\text{resistance (R)}}$$

and for the magnetic circuit as

$$\text{Flux} = \frac{\text{magnetomotive force (MMF)}}{\text{reluctance}}$$

18-6. So far, we have discussed the similarities between magnetic circuits and electric circuits. There are, however, several important differences that we must consider. The resistance is a constant in an electric circuit and can be determined by the ratio of the voltage to the current (discounting the heating effect). The reluctance, however, is not a constant in a magnetic circuit but depends on the flux (strength of the field).

18-7. Another important difference between an electric circuit and a magnetic circuit is that a current flows in the electric circuit as the electrons move from one point to another point. The

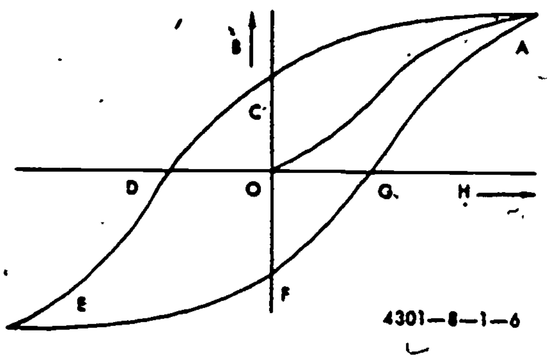


Figure 102. Hysteresis loop.

flux does not move in the magnetic circuit but is merely an indication of the direction and intensity of the magnetic field.

18-8. When we discuss magnetic circuits, we must consider hysteresis and its effect on magnetic circuits.

18-9. *Hysteresis.* When a piece of iron is magnetized, considerable energy is expended in lining up the magnetic molecules in the iron in a definite pattern. For a given iron core, the flux density increases along the curve OA as the magnetizing force is increased, as shown in figure 102. What happens when the magnetizing force is decreased to zero? The flux density does not decrease along the AO curve to zero but decreases more slowly along the curve AC. As shown in figure 102, when the magnetizing force reaches zero, a certain value of flux density remains (OC). This is caused by the residual magnetism. In other words, the iron continues to be a magnet even after the magnetizing force is removed. If, at this point, the magnetizing force were reversed, the field intensity would be in the opposite direction, but the flux density would have the same polarity as before because of the *residual magnetism*. Now, increasing the magnetizing force gradually reduces the flux density along the curve CD to zero at point D in figure 102. It requires a magnetizing force of OD to reduce the flux density to zero. Force OD is called the *coercive force*.

18-10. As the magnetizing force continues to increase, the iron core becomes magnetized along DE (fig. 102) in a direction opposite to its original magnetization (OA). At point E, the magnetizing force is again decreased to zero. The flux density decreases more slowly along the line EF. By the time the magnetizing force reaches zero, the flux density has a value of OF, which is equal to OC (fig. 102). This is due to the *residual magnetism* in this direction. As the magnetizing force is again increased in the original direction, the flux density decreases along the curve FG to zero. If the magnetizing force continues to increase, the flux density follows the path GA.

18-11. Note that the flux density of the iron core does not become zero each time the magnetizing force becomes zero. A coercive force is necessary to reduce it to zero. This lagging of the magnetic flux behind the magnetizing force that produced it is known as *hysteresis*. In figure 102, the entire curve ACDEFGA is known as the hysteresis curve.

18-12. When the magnetism of an electromagnet is reversed rapidly, as in an alternating current circuit, the iron core becomes heated, and considerable energy is wasted in producing this heat. This loss is called hysteresis loss and can be considered as a kind of molecular friction caused by the reversal of the magnetic molecules which iron and other magnetic materials possess.

18-13. *Basic magnetic amplifier.* The output voltage of many AC generators is controlled by a magnetic amplifier type of voltage regulator. The magnetic amplifier is a relative simple device. The construction consists of two or more coils wound around a circular iron core.

18-14. Magnetic amplifier cores are usually ferromagnetic material. This material reacts to a magnetizing force very quickly; also, ferromagnetic materials become totally magnetized as a result of a small magnetizing force. Therefore, a ferromagnetic core is ideal for magnetic amplifier operation because the core reacts quickly, and a small force is needed to realize total reaction.

18-15. The coils around a core are named by their function. Input or control windings determine the level of flux density within the core. Output or load windings determine current flow from a generating source to a load.

18-16. Once a core has been magnetized to its maximum value, any additional increase in the magnetizing force will not increase the level of flux density. This point is *saturation*—point A or B on figure 102.

18-17. Putting all the above parts together, a sequence of reactions with a magnetic amplifier would go like this.

- The control-winding current establishes the flux density level in the core.
- The core reacts to an AC current in the load winding according to the level of flux density.
- The generating source feels the load winding plus the load and delivers the appropriate current flow.

18-18. The key to the whole operation is the *level of flux density*. Recall the area in the last

chapter concerning inductors, CEMF was developed in an inductor whenever the level of flux density was increasing or decreasing. At this point, we are inserting the condition of a controlled level of flux density which limits CEMF and in turn, limits the opposition the load winding can offer the generating source.

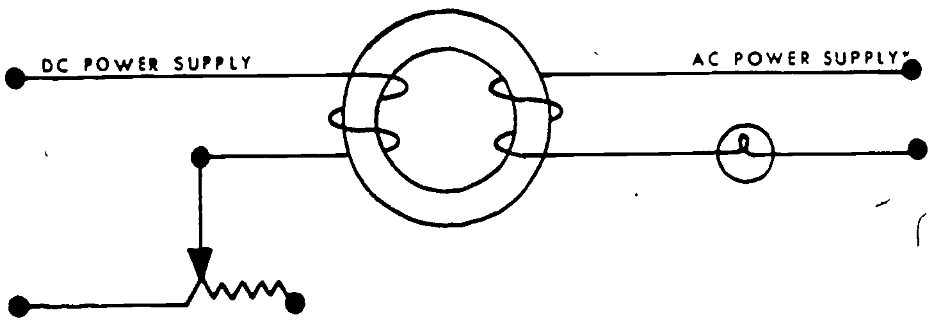
18-19. To more fully understand the operation of a basic magnetic amplifier, an example will be used. Look at figure 103, part A. The control winding is connected to a DC power source and a variable resistor. The load winding is connected to an AC power source and a light bulb. The objective is to control the intensity of the light bulb, using the variable resistor.

18-20. The initial conditions are that the DC power source remains constant, the AC power source remains constant, the variable resistor is set at minimum resistance, and the current flow in the control winding is sufficient to produce *saturation* of the core.

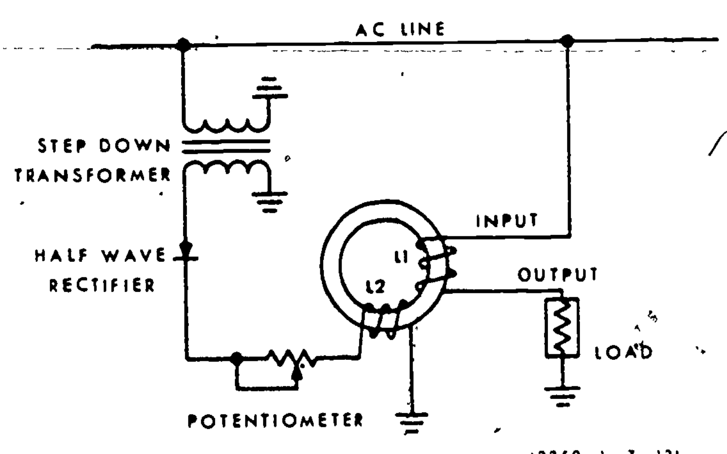
18-21. The generating source feels no reactance in the load winding and delivers maximum current flow to the lamp. The intensity of the lamp is very bright.

18-22. Sliding the wiper of the variable resistor from no resistance to full resistance will be accompanied by a decrease in the intensity of the lamp. As the current through the control winding decreases, the level of flux density decreases. Reactance can now be felt in the load winding and the AC generating source adjusts its current accordingly. This example is not usable for controlling voltage outputs of generators, but the operation shown by this example illustrates the theory of magnetic amplifiers. If we control the level of flux density, we can control the reactance within the load winding; result, we can control current flow from the generating source to the load.

18-23. *Simple magnetic amplifier*. Now that you are familiar with the principles of a magnetic



A



B

Figure 103. Basic magnetic-amplifier circuits.

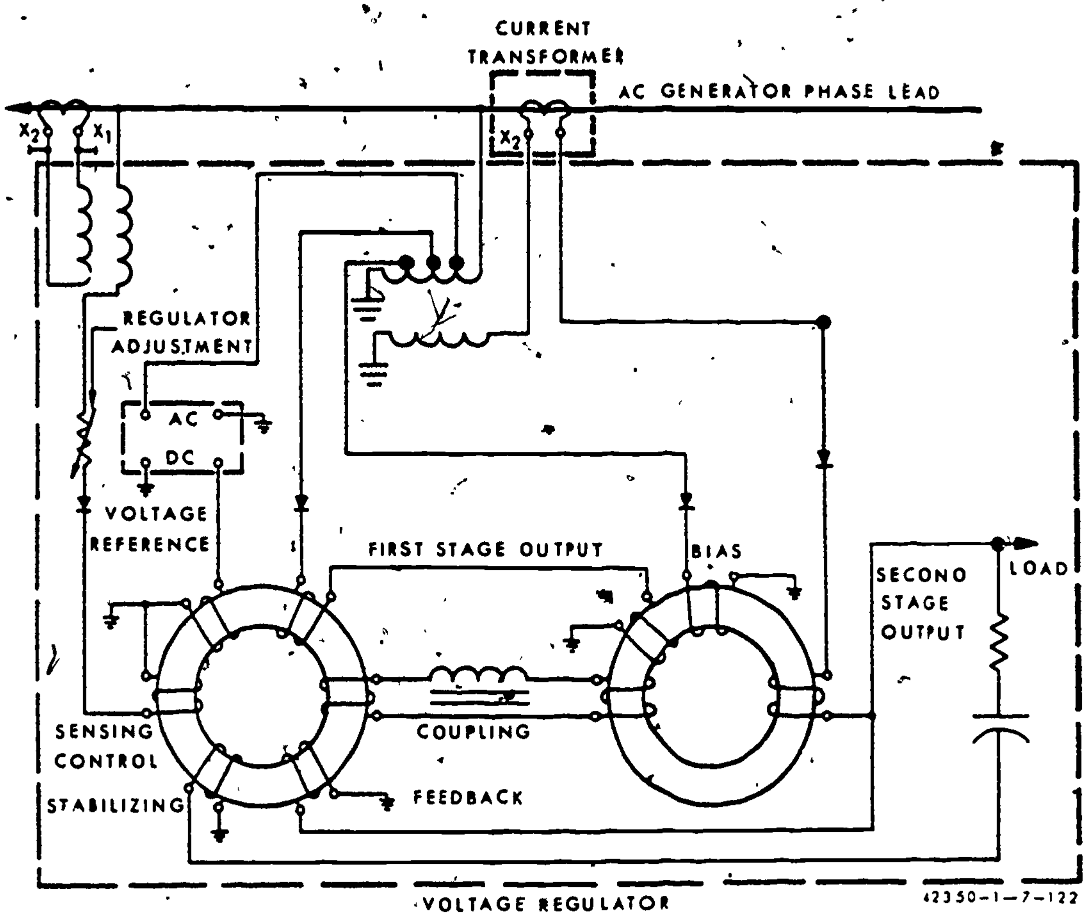


Figure 104. Simple voltage regulator.

amplifier, let us discuss a more practical amplifier, such as that shown in figure 103, part B.

18-24. First, let us assign some values to the circuit and see what happens when the DC in the control coil L2 is varied. For simplicity, assume that coil L2 has an input range variable from 0 to 30 milliamperes, but the potentiometer is set at midrange, or 15 milliamperes. The core is magnetized to the point where 1 ampere input to coil L1 results in only 0.25 ampere output across the load. What happens if the output of the control coil L2 is increased while the AC input remains the same? By increasing the flux of the core, the inductance (and therefore the reactance) of coil L1 will decrease and the output of coil L1 will increase although the input to the amplifier remains the same. If the DC in the control coil L2 is decreased, the amount of flux in the coil is also decreased. This means that the reactance of coil L1 is increased and less current will flow to the load, even though the input to the amplifier remains constant. Thus, by varying the output of the control winding, the output of the amplifier may be increased or decreased by decreasing or increasing the reactance of the coil even when the input is held at a constant value. This type of magnetic amplifier may also be called a saturable reactor, since the reactance of the coil is determined by the degree of saturation of the core.

18-25. The term "amplifier" as used here is something of a misnomer. Nothing is really amplified. The word "amplifier" really denotes the control of substantial amounts of *power* by relatively small voltage or current signals.

18-26. **Magnetic Amplifier Voltage Regulator.** Earlier in this section it was mentioned that one of the uses of a magnetic amplifier was in voltage regulating circuits. Although voltage regulators are covered in greater detail later in this course, right now it is important that you learn the application of a complete mag-amp circuit as used in some voltage regulators.

18-27. So far, we have considered only circuits in which the input and, by implication, the load were held at constant values. To see the effect of varying inputs and varying loads, examine figure 104. Note that several additional windings have been added to the coil, and there

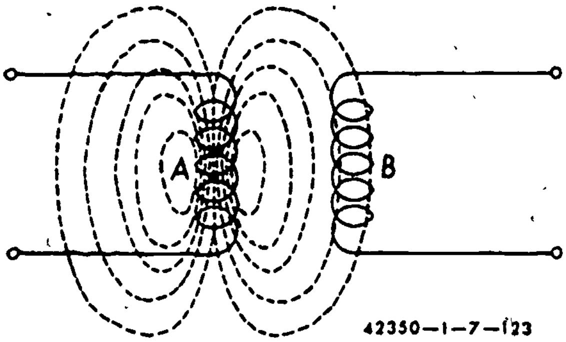


Figure 105. Mutual inductance.

are two separate coils which are referred to as the first stage and the second stage of amplification. Let us begin with the sensing winding. In this circuit the sensing winding is also the control winding for the first stage of amplification. The first stage sensing winding is connected to one of the AC generator phase leads and receives a signal proportional to the AC value in that lead. Note that the voltage reference unit is also connected to the AC generator phase lead. Its purpose is to maintain a constant reference signal over a wide range of generator output. The reference signal is compared magnetically with the sensing, and the resultant value of magnetic flux, which is called generator error, controls the first stage output.

18-28. The output of the first stage is used to power the control winding of the second stage and, thereby, control the second stage output to the load. (Later in this course you will find that the load refers to the exciter field of the generator.) The first stage magnetic amplifier uses additional windings which assist in the control of output circuit.

18-29. The first stage output is fed into a second stage DC control winding, which is compared to the bias signal. The bias circuit is very similar to the reference circuit except that the bias circuit signal is variable and is proportional to the voltage in the AC generator phase lead. The magnetic resultant bias and the first stage output signals control the second stage output voltage. The second stage is called the power stage, and it supplies the DC power to the load. The amount of DC power supplied to the load determines the level of output voltage of the AC generator.

18-30. To help maintain system stability, the feedback circuit shown in the illustration takes a rate-of-change signal from the second stage output and feeds it into a control winding of the first stage. This signal is in such a direction as to oppose any change that occurs because of transient load conditions. The feedback circuit may be thought of as a stabilization circuit used to prevent overcontrol of the circuit. Any time there is a change in the output of the second stage, it will be sensed by the feedback circuit. Part of the change is sent back to the first stage where it has a damping effect on the first stage output. Since the first stage output determines the second stage output, this damping effect provides protection against fluctuating output voltages in the second stage.

18-31. Additional damping is provided by the coupling circuit between the first and second stages. The inductor shown in the illustration senses a rate-of-change signal. A sudden increase or decrease of the load connected to the second stage will immediately create a signal in the winding that opposes the change, and thus tend to damp it out. A slow increase or decrease will usually not affect the coupling circuit.

18-32. Another use for magnetic amplifiers is in frequency control units. Since there are many factors that must be considered in these circuits, such as the relationship between generators operating in parallel and the effects of unequal load division among them, it will be best to discuss these units in the section on AC generator systems. That section will also discuss more complex voltage regulator systems in detail.

18-33. **Transformers.** There is a need for many different voltages in modern airplanes. The range of these required voltages varies from 3 volts up to 1000 volts or more. With a direct-current system, these higher voltages are almost impossible to obtain, so other means have been devised to obtain them. To have a separate source of electrical energy for each of the various voltages required would result in an extremely complex power distribution and control system. For this reason, the primary power system voltage used in airplanes today is somewhere between the maximum and minimum requirements of the equipment installed. The voltage is modified by one of several means to obtain the specified voltage for each piece of equipment. Where the principal source of electrical energy is a direct-current generator, lower voltages are obtained by placing resistance in series with the equipment to be operated. The value of these resistors is carefully determined so that the correct amount of current reaches the operating unit at its normal operating voltage. The difference in voltage between the source voltage and that at the operating unit is dissipated by the resistor in the form of heat energy, which, for all practical purposes, represents a power loss. Where a higher DC voltage is desired, the low-voltage DC is used to drive a motor, which, in turn, drives a small

high-voltage DC generator. In this transformation, there are substantial power losses, because no mechanical device can be frictionless and no machine is 100 percent efficient. Then, too, there is always the problem of insulation on the rotating member of a high-voltage DC generator and the possibility of failure at an inopportune moment. Practical electrical power installations today use one or more sources of alternating voltage. By using some of the electrical principles covered in the preceding areas, the voltage is changed to another value by a transformer whenever a voltage other than source voltage is required.

18-34. **Operation.** A transformer is basically a device that makes possible the transfer of electrical energy from one circuit to another. A transformer does not change the form of the applied energy, but it is capable of changing the values of the transferred current and voltage to different values. From the study of electromagnetism and inductance, you learned that a wire or coil in which a current flows has a magnetic field about it, and you also learned that the amount of current determines the relative strength of that magnetic field. You also learned that if the magnetic field cuts through a conductor, a voltage will be induced in the conductor. These are the basic principles involved in transformer operation; hence, it is essential that you thoroughly understand them. For this reason let us begin with a brief review of mutual induction and the principles of transformer operation.

18-35. If we have two straight conductors parallel to each other, the magnetic field caused by a current flowing through one circuit moves across the second conductor inducing a voltage in it. The first circuit is called the primary (p), since it is from this source that the magnetic field is produced. The second circuit is called the secondary (s), because it is the circuit in which the voltage is being induced.

18-36. When a current begins to flow, building up rapidly in magnitude from zero to its maximum value, it produces a rapidly expanding magnetic field about the primary. Again, it is important to remember that motion is necessary to induce a voltage. The motion in this case is the expanding field which cuts across the secondary, inducing a voltage in it, as shown in figure 105. This induced voltage, however, is an instantaneous action. When the current in the primary reaches its maximum value, the resultant magnetic field is at its maximum strength, and the magnetic field at this time is neither expanding nor collapsing. Thus, the flux is not moving in relation to the secondary winding, and no voltage is being induced in the secondary at this time. This does not mean that the magnetic field is not present. The field is still there, since it is being sustained by the current flow in the primary. As long as the current flows at a steady rate, the flux will be maintained at a steady strength, which results in no field motion and no induced voltage in the secondary.

18-37. At this point, you should consider several facts about the polarity relationship between the primary and secondary circuits. The instantaneous voltage that is induced in the secondary is of opposite polarity to the voltage of the primary. This fact has been discussed in the chapter on inductance.

18-38. What action would you expect if the primary circuit were suddenly opened? When the circuit is broken, primary current must stop. The primary magnetic field, which is dependent upon the primary current, must collapse, and in doing so, must once again move across the secondary. Since the field is moving across the secondary wire in the opposite direction, the induced voltage must now be of opposite polarity from what it was during buildup.

18-39. From this, it can be seen that a transformer would be of little value if DC were applied to the primary, since a voltage would be induced only when the circuit was completed or interrupted. On the other hand, if a pulsating DC or AC were applied to the primary, the magnetic field would be constantly building up and collapsing, thus continually inducing a voltage in the secondary.

18-40. This method of transferring electrical energy from one circuit to another is known as *mutual induction*. As a transformer, a single straight length of wire would be a poor device for the transfer of power. The magnetic field about a straight conductor is weak, and the secondary would offer only a short length of wire in which to induce a voltage. If both the primary and secondary were wound as coils, the transferred voltage would be greatly increased. Even with this refinement, however, the transformer would still not operate at maximum efficiency. With an airgap between the coils, all the flux that builds up about the primary would not cut across the secondary. The flux losses in this arrangement, referred to as flux leakage, would act to reduce the efficiency of the transformer. To reduce flux leakage, a suitable core material such as iron can be inserted between the coils to provide a low reluctance path for the magnetic lines of force.

18-41. **Transformer Construction.** The absence of moving parts in the construction of a transformer makes it a remarkably efficient de-

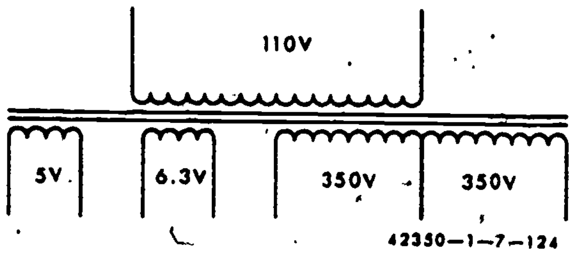


Figure 106. Typical power transformer.

vice. When moving parts are eliminated from a device, mechanical friction (which is a major cause of power losses) is eliminated.

18-42. Transformers are designed to keep electrical power losses to as small a value as possible. These losses may be divided into two classes, iron and copper losses.

18-43. *Iron losses.* Iron losses that occur in the core of a transformer are caused by hysteresis and eddy currents, both of which have been mentioned previously. Both factors produce heat and represent losses that act to reduce the power output of the transformer.

18-44. The first factor to be considered is the loss caused by hysteresis. Hysteresis in an iron core means that the magnetic flux or lines of force lag behind the magnetizing force that is causing them. Friction is caused by the molecules trying to aline themselves with a constantly changing magnetic field that is produced by changes in the direction of current flow through the primary coil. The friction produces heat, which is wasted energy.

18-45. When the core of the transformer is magnetized, the molecules of the core material will be alined in one direction. As the magnetizing force decreases to zero, the magnetizing action leaves the molecules alined in a particular manner for a period of time. The magnetism that is left in the core material after the magnetizing current has stopped flowing is called *residual magnetism.* Whenever AC is used to magnetize the core, whatever residual magnetism is placed in the core during one half-cycle must be overcome in the next half-cycle before the polarity of the core can be reversed.

18-46. The second iron loss that must be considered is that which occurs as a result of *eddy currents.* Iron is a fairly good conductor of electricity, but not as good as copper. When alternating current is applied to the winding around a solid iron core, a varying magnetic field will move across the core and induce a voltage in the core material. *This voltage sets into motion a large number of currents in the core;* these are known as *eddy currents.* Since the solid iron core has a large cross-sectional area which has little resistance, large numbers of eddy currents circulate and produce unwanted heat.

18-47. These problems are overcome by using thin sheets (laminations) of soft iron or a special transformer steel containing silicon in the construction of transformer cores. These laminations are oxidized, varnished, or otherwise have their flat surfaces treated with an insulation layer. They are then placed together in such a way that there is no electrical contact between them. A complete transformer core consists of many of these thin laminations stacked together to provide a large core area and, at the same time, to restrict the travel of eddy currents. Eddy currents still exist, but their travel is restricted to a point where the resulting heat losses are reduced to a minimum.

18-48. *Copper losses.* Copper losses are those that occur within the windings of the transformer. They are due to just one thing, *the heat generated by the current in the conductors.* You need to remember that the resistance of copper and most other metallic conductors increases as the material gets hotter. This means that if the heat resulting from the iron and copper losses is allowed to accumulate, the windings will get hotter. The hotter the conductors get, the higher their resistance becomes, which in turn increases the power losses due to excessive heat.

18-49. The windings of the transformer are designed to be as short in length and as large in diameter as possible to decrease the resistance and reduce the heat, and thus contribute to transformer efficiency. In large power transformers, the overall loss due to heating is reduced by special cooling devices; for example, oil baths, radiators, or air blowers.

18-50. *The total transformer power loss is the sum of the copper loss plus the iron losses.* Because of these losses the transfromer is not 100-percent efficient; therefore, the actual power

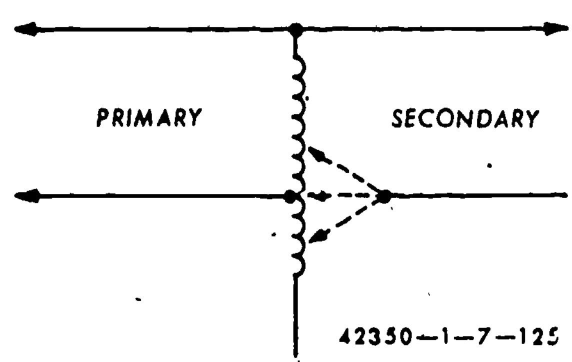


Figure 107. Autotransformer.

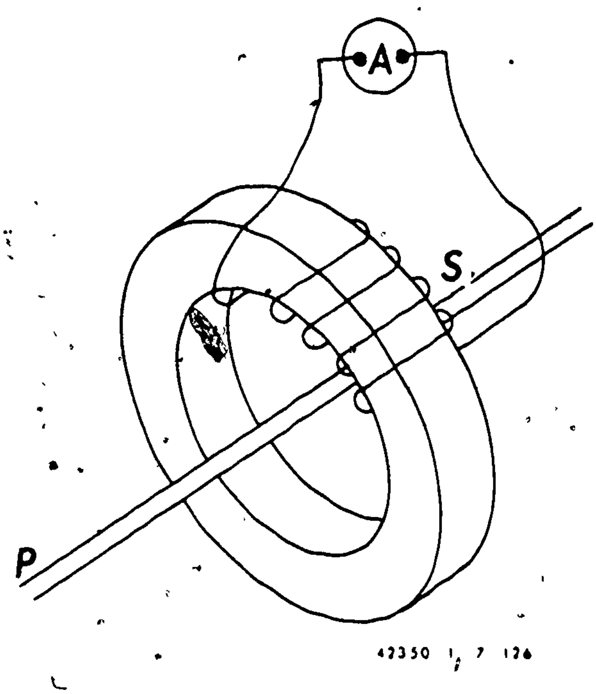


Figure 108. Current transformer.

taken from the transformer secondary winding will never equal the amount of power applied to the primary winding.

18-51. **Power Transformers.** So far, the only transformers that have been discussed are those that have only one secondary winding. Often there are several secondary windings, each providing a separate voltage for different purposes. Figure 106 shows a schematic diagram of a typical power transformer used in many circuits. Leads on this type of transformer are usually color coded for easy identification. If the leads are not color coded, they will be identified by numbers on the transformer. In either case, the color code or the numbers will be found on the schematic circuit diagram for that particular piece of equipment.

18-52. Another type of power transformer is called an autotransformer. This unit is sometimes found in aircraft lighting systems but is more likely to be found in the electric shop. It is used to provide a wide variety of voltages for testing purposes. It is known as the autotransformer because the primary and secondary windings are actually one winding. Many of these units in general use today have the trade name "Variac." Figure 107 is a schematic diagram of an autotransformer. The movable secondary tap enables the user to select a voltage value to suit his need. It is possible to obtain transformer action with such a coil if a connection is made somewhere along the winding between the extreme ends. If a step-up voltage effect is desired, the winding between the input leads in the primary and the entire winding acts as a secondary. There is a 180° phase shift between primary and secondary voltages. The core in this type of transformer is made in the form of a ring and the winding is usually in the form of a single-layer winding covering almost the entire surface. A manually operated control shaft carries an arm and a brush that is so arranged as to make contact with each turn of the winding as the control shaft is rotated.

18-53. **Current Transformers.** Current transformers are used for controlling and sensing circuits. When used for this purpose, the transformer has no primary winding; the current in the secondary is induced by the current flowing through the conductor that passes through the center of the transformer, as shown in figure 108. You will find many of these transformers on multigenerator AC systems. They are used in such circuits as voltage regulation, frequency control, and load protection. They are also used to furnish sensing current to KW/KVAR meters.

19. Semiconductors.

19-1. There are many solid-state devices used in the electronics field; you will be mainly concerned with crystal diodes and transistors.

19-2. The operation of crystal diodes and transistors is based on the peculiar properties of semiconductor materials such as germanium and silicon. Semiconductors are materials that are roughly halfway between the metals and the insulators in their ability to carry current. These materials are brought to an exceedingly high degree of purity and then "poisoned" by the addition of very carefully controlled amounts of other elements.

19-3. **Semiconductor Operation.** The two materials most generally used for semiconductor devices are, as we mentioned before, germanium and silicon. Each of these materials has its own advantages, but an explanation of these advantages is beyond the scope of this course. Fundamentally, both of these materials react electrically in the same manner. When germanium is in its pure state, it is very nearly an insulator; that is, it has very few electrical charge carriers. Pure silicon also is a poor conductor of electricity. Both of these elements have four-valence electrons. Valence electrons are the electrons in the outer shell of the atom. Theoretically, they are more loosely bound to the atom than electrons closer to the nucleus of the atom.

19-4. By the addition of certain very small amounts of a three- or five-valence electron material to the pure germanium or silicon, they take

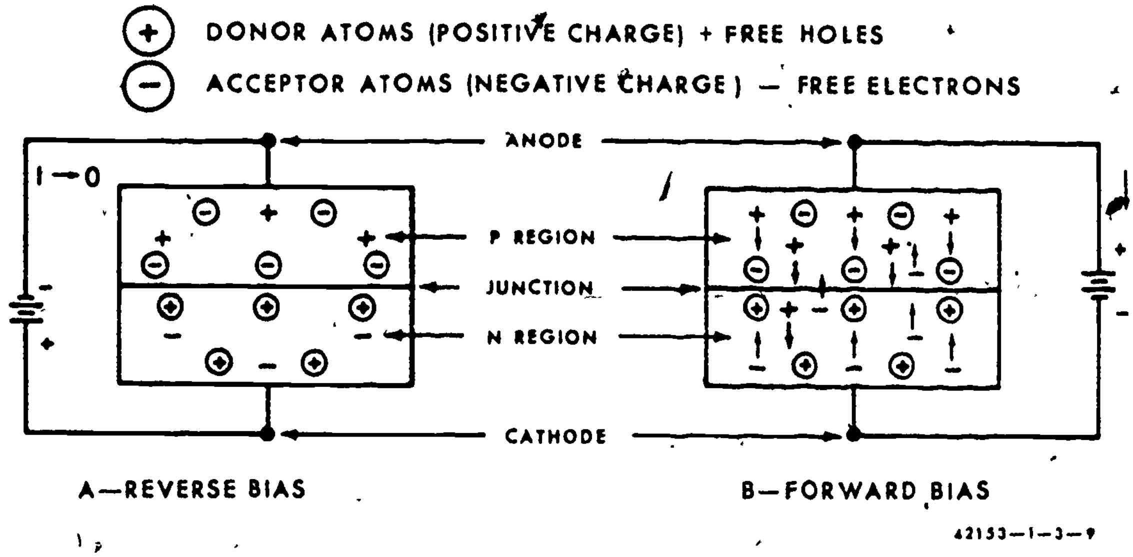


Figure 109. Two conditions of bias in a PN rectifier.

on the properties of either an *acceptor* or a *donor type material*. Briefly, the *acceptor type* of material (three-valence electron material added) is effectively deficient in electrons. This lack of electrons within the crystalline structure causes the material to be known as a P type. You may also hear the word "holes" associated with P type material.

19-5. The *donor type* of material (five-valence electron material added) is effectively overloaded with electrons. This surplus of electrons within the crystalline structure causes the material to be known as an N type.

19-6. The flow of electricity in a semiconductor occurs by means of the free holes and free electrons in the crystalline structure of the material. One very important point to remember about the theory of semiconductors is that of space charge neutrality. This means that the total number of positive charges in any region of a semiconductor equals the total number of negative charges under conditions of small voltage differences within the semiconductor. Thus, we arrive at a practical point where, by applying voltages externally, this balanced charge condition is upset and current flows.

19-7. **PN-Junction Rectifiers.** When a P type region and an N type region are formed in the same piece of germanium or silicon, a rectifier or diode is formed. The boundary between the P and N regions is called a junction. The P region is called the anode, while the N region is called the cathode. The interface between the P and N materials is called the junction. These regions and their relationship to each other are illustrated in figure 109 where two conditions of bias are shown. When the anode of the rectifier is made negative with respect to the cathode, the rectifier allows almost no current to flow. This condition is called reverse bias. The theory behind this action is that the electrons in the N region and the holes in the P region are both

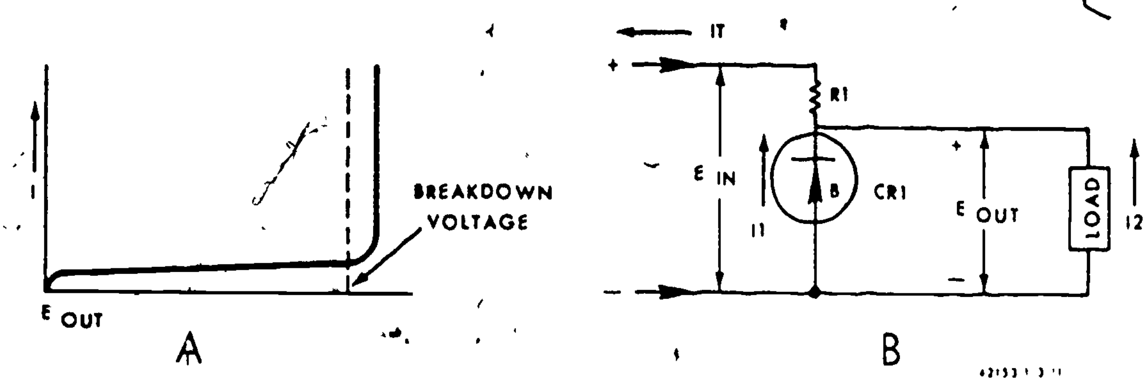


Figure 110. Zener diode.

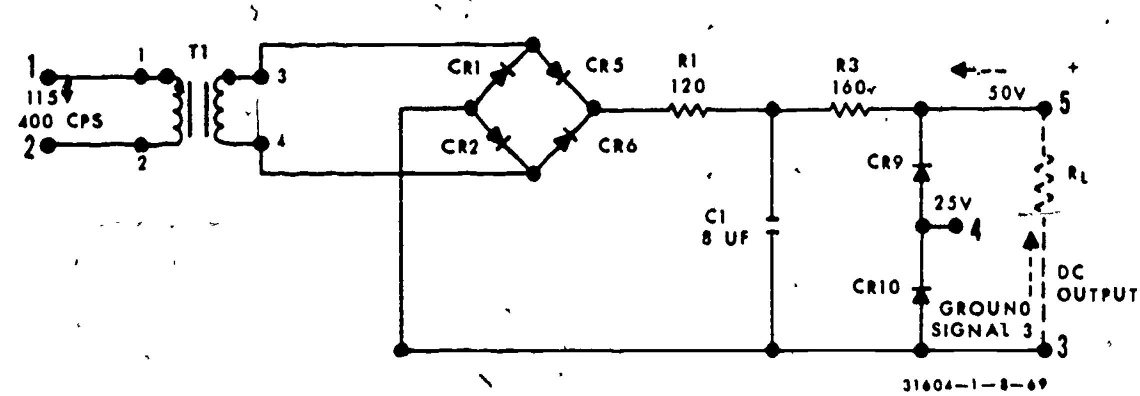


Figure 111. Full-wave rectifier.

repelled from the junction. This leaves no charge carriers near the junction, and so no electricity can flow through the rectifier. However, if an exceedingly high reverse-bias voltage is applied to the rectifier, the barrier breaks down. This breakdown, if uncontrolled (too much current is allowed to flow in the reverse direction), overheats and ruins the diode. At the breakdown point (too high a reverse voltage), the "leakage-current" electrons can gain enough energy to free additional electrons from the semiconductor atoms causing what is known as *avalanche multiplication*. This means simply that each electron that moves under this high voltage collides with the semiconductor atoms and frees additional charge carriers; these add to the total current. Under avalanche conditions, the I^2R (power) developed across the junction may ruin the device. The word "may" is used because the magnitude and duration of the current are the determining factors.

19-8. Again referring to figure 109, note a condition known as forward bias. The theory here is that the electrons in the N region move across the junction and unite with holes in the P region. Also, the holes in the P region move across the junction and unite with the electrons in the N region. The movement of these negative and positive carriers across the junction controls the current in an external circuit. The result of forward bias is considerable current flow for a small applied voltage.

19-9. **Zener Diode.** A Zener diode is a specially processed silicon diode that exhibits properties similar to a gas diode. A graph of the current through and the voltage across a reverse-biased diode is shown in A of figure 110. Note that with a certain value of reverse voltage, the current increases rapidly while the voltage across the diode remains almost constant. The voltage at which this action occurs is called the breakdown or Zener voltage. When the reverse-biased diode is used to take advantage of this characteristic, it is called a Zener diode. The breakdown diode can be used as a voltage regulator, as shown in B of figure 110.

19-10. When the load current I2 increases (within limits), the total current drawn from the source E_{IN} does not increase. The increased current is diverted to the load from Zener diode CR1; the voltage across the breakdown diode CR1 and the load remains almost constant. A decrease in current I2 drawn by the load causes a corresponding increase in current I1 drawn by breakdown diode. Under these conditions the total current IT drawn from the source E_{IN} remains constant, so that the voltage output E_{OUT} again remains practically constant.

19-11. If the source voltage E_{IN} increases, total current IT drawn from the source also increases. The voltage drop across resistor R1 increases by the amount of increase in source voltage, and current I1 increases by the amount of increase in current IT. The load current I2 and the load voltage E_{OUT} remain nearly constant. A decrease in source voltage is compensated for in the same manner by a decrease in voltage drop across resistor R1 and a decrease in current I1 through the diode.

19-12. The *voltage regulator* discussed above is capable of maintaining a constant load voltage, regardless of the variations that occur in either the source voltage or the load current or both. Depending on the characteristics of the particular breakdown diode, the breakdown voltage can be any value from 2 volts to 200 volts.

19-13. At this point, let's discuss the difference between a solid-state rectifier and a solid-state diode. As you know, both of these units have a higher resistance to current flow in one direction than in the other. The main difference is one of terminology. The rectifier is a unit that is normally used in circuits handling large

amounts of electrical power, while diodes are used in signal type circuits where the power requirements are relatively small.

19-14. **Rectifier Power Supplies.** The power supply units that furnish the direct-current power requirements (other than 28 volts) are full-wave, bridge, and dry rectifiers operating above and below signal ground potential. *Four* individual rectifier elements are utilized. Now let's simplify these statements a little bit. About the best way to gain a good understanding of full-wave rectification is to follow power through a partial schematic of a rectifier similar to the one used in an aircraft. Study figure 111 as you follow this explanation.

19-15. The power applied to the primary of the transformer (T_1) is 115 volts at a frequency of 400 Hz. To follow the direction of current through the bridge rectifier assembly, we must assume an applied voltage at some instant. Let's assume that point 3 of T_1 is positive with respect to point 4. Thus a positive potential exists at the junction of CR1 and CR5. A negative potential is therefore applied to the junction of CR2 and CR6. Electron theory of current flow tells us that the current must flow from a point of low potential to a point of high potential. Because of the unidirectional characteristics of the rectifiers, current at the junction of CR2 and CR6 can go only through CR2 (against the arrow). Since rectifier CR1 acts as an open, the current must flow out through the load (R_L) and back to the junction of CR5 and CR6. The current cannot flow back through CR6 because of the lower potential at the opposite end of CR6. So, the current passes through CR5 and back to the secondary of T_1. This occurs for one-half of a cycle. On the other half of the cycle, the voltages applied to the junction of CR1 and CR5 and the junction of CR2 and CR6 are reversed. Now the junction of CR1 and CR5 becomes negative, while the junction of CR2 and CR6 becomes positive.

19-16. The negative potential at the junction of CR1 and CR5 will cause current to flow through CR1. The rectifier CR5 is biased off at this time. The rectifier CR2 is biased off so the current will flow out through the load and back to the junction of CR5 and CR6. The rectifier CR5 is biased off so the current flows through CR6 and back to the secondary winding of T_1.

19-17. You will notice both half-cycles of the AC input power are utilized, and for both half-cycles the current flows in the same direction through the load. Also, the output frequency will be double the input frequency. The resistors R1 and R3 plus capacitor C1 form a filter network to help smooth out the pulsations. Smoothing out the pulsations effectively causes the direct current to be at a constant voltage level as applied to the load. The Zener diodes CR9 and CR10 are voltage-regulating devices. If the voltage tends to rise above their breakdown rating, they will act as a shunt across the load and thus reduce the voltage. If the voltage tends to drop below a preset value, the diodes will effectively become an open circuit and cause all of the voltage to be applied to the load. The diodes CR9 and CR10 are each 25-volt units. This means that they will pass current at a voltage potential difference of 25 volts. Thus, two of them in series form a 50-volt regulator. A tap between them forms a 25-volt regulator. This is all illustrated in figure 111.

19-18. Now, assume that we have two PN junctions in one crystal, one biased in the forward direction and the other in the reverse direction. Then you apply a signal to the low resistance section (PN junction biased in the forward direction) and take an output from the high-resistance element (PN junction biased in the reverse direction). When the output is developed in the external circuit, you find that you have increased the power. You have produced a power gain. The combination of PN junctions has *transferred* the signal from a low-resistance circuit to a high-resistance circuit. Thus came into being the word "transistor," which is a contraction of the words "TRANSfer" and "resISTOR."

19-19. **Transistors.** Since you have had formal schooling on transistors at some time in the past, the material covered in the following paragraphs is mainly to refresh your memory and broaden your knowledge of transistorized circuits. Possibly a few of the circuits explained later in this discussion will be new to you. But remember, the more background knowledge you acquire, the easier it will be for you to understand the systems.

19-20. What is a transistor? It is a solid-state device used for signal and power amplification, signal inversion, and related applications where its small size is especially adaptable to the miniaturization of electronic equipment. The transistors that are of prime importance are the junction type. By recalling the explanation of semiconductor diodes, you can move easily to junction transistors. The semiconductor diode has a junction between an area of P type material and an area of N type material. By forming a layer of one type of material between two layers of the other type material, a junction transistor is formed. The transistors thus formed are

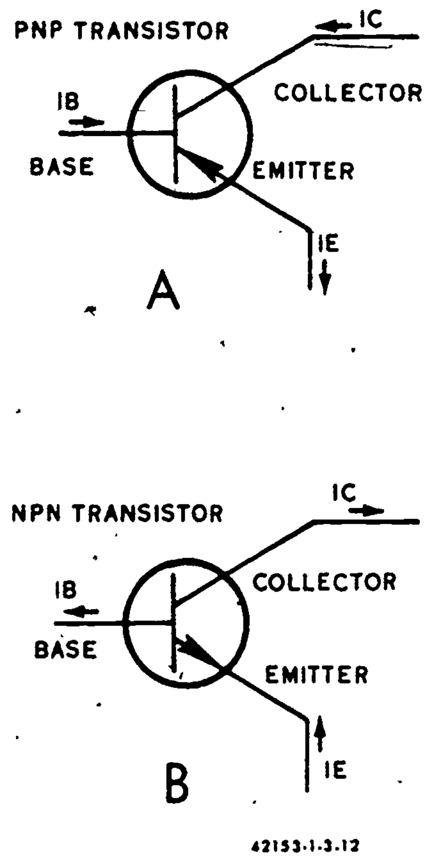


Figure 112. Schematic symbols of transistors.

known as PNP or NPN types, depending on which type material is in the center.

19-21. By studying figure 112 you become familiar with the schematic symbols for transistors. Part A of figure 112 shows the terminal names and the direction of current flow for a PNP transistor, and part B shows the terminals and the direction of current flow for an NPN transistor. Notice that the arrow in the emitter lead (IE) is always against the direction of electron flow. The direction of this arrow is an indicator of the type of transistor. The arrow pointing toward the base means a PNP transistor, and the arrow pointing away from the base means an NPN transistor. Having two different types of transistors means that the circuit polarities for one must be reversed for the other. For a PNP transistor, the collector is negative with respect to the emitter. For an NPN transistor the collector is positive with respect to the emitter. When the current flow in the emitter lead is away from the transistor (PNP type), the current flow in the base lead (IB) is into the transistor. When the current flow in the emitter lead is into the transistor (NPN type), the current flow in the base lead is away from the transistor.

19-22. Now let's examine a simple single stage of AC amplification. Follow through and study figure 113 during this explanation. The input signal is an AC sine wave and is coupled to the base of the transistor by a coupling capacitor. Resistors R1 and R2 form a voltage divider network. This network is used to establish a bias voltage on the base of the transistor. The correct bias voltage causes the transistor to operate in its linear range so that it does not distort the output signal wave shape. Resistor R3 also enters the biasing circuit because some current flows from ground, through R3, into the emitter lead and out the base lead to the junction of R1 and R2. The capacitor in parallel with R3 offers a low-resistance path for ac signals.

19-23. There is current flow through the transistor and R4 to the positive side of the power supply at all times. The input signal varies the ability of the base to conduct current. This variation of current flow causes a variation in the voltage drop across R4. The changing voltage drop is reflected across the output capacitor. When the input signal goes in a positive direction, the current flow through the transistor increases. This causes a greater voltage drop across R4. The net result is a decreasing output-signal voltage with an increased input-signal voltage. This phase change is known as phase inversion. The actual amount of voltage amplification is dependent on the particular circuit construction.

19-24. **Transistor Amplifier Circuits.** There are three ways in which a transistor may be used in an amplifier circuit. Each way allows some variation in relationship between the input signal

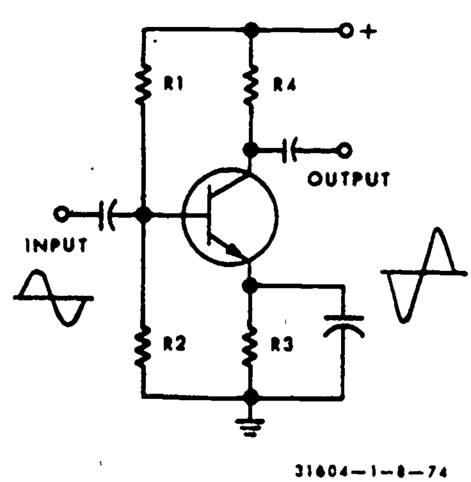


Figure 113. Typical AC amplifier.

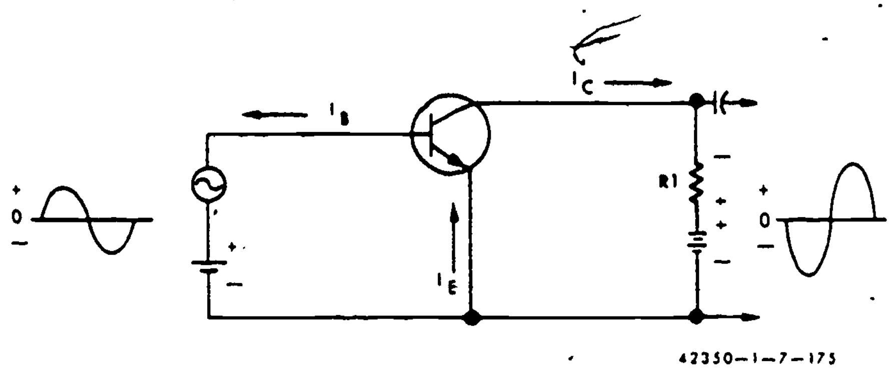


Figure 114. Common-emitter (CE) ampliifer.

and the output signal. You should be familiar with these configurations in order to better understand what happens to a particular signal as you follow it through a system. In the following paragraphs, we review the common-emitter (CE) amplifier, then follow this by reviewing the common-collector (CC) amplifier, and the common-base (CB) amplifier.

19-25. *Common-emitter (CE) amplifier.* The common-emitter (CE) amplifier, shown in figure 114, is a simplified schematic of the circuit shown in figure 113. The name "common-emitter" is derived from the fact that the emitter terminal is common to both the input and output circuits. The common-emitter circuit is also known as a grounded-emitter circuit. The following discussion is related to figure 114 with an NPN transistor. The battery in the base-to-emitter circuit supplies the bias voltage, while the battery in the collector-to-emitter circuit is the main transistor power supply. The input signal is applied between the transistor base and ground. The output signal is taken between the collector and ground. Resistors R1 in figure 114 and R4 in figure 113 both serve the same function as load resistors. An examination of the input and output graphs reveals a phase inversion of the signal and a gain in signal amplitude.

19-26. *Common-collector (CC) amplifier.* The common-collector (CC) amplifier is shown in the simplified schematic of figure 115. Here again we have a bias voltage source and a power voltage source. Notice that the collector is common to the input and output circuits. The load resistor is shown in the common (collector) line rather than in the emitter line. This causes the output signal to be in phase with the input signal. Consider an instant of time when the input voltage is positive, as shown by the line AB. This positive input signal causes the total collector current to increase. The increased collector current causes the top point of the load resistor R1 to become more positive with respect to the lower end. The result is shown by the line AB on the output waveform. The CC circuit is also known as a grounded-collector circuit or as a follower type circuit, and does not produce phase inversion. This type of circuit is frequently used as an isolation amplifier and has an amplification factor of less than one.

19-27. *Common-base (CB) amplifier.* The common-base (CB) amplifier is shown in simplified form in figure 116. In this case we have a bias battery in the base-to-emitter circuit. The power battery is in the base-to-collector circuit. The base is common to both the emitter and the

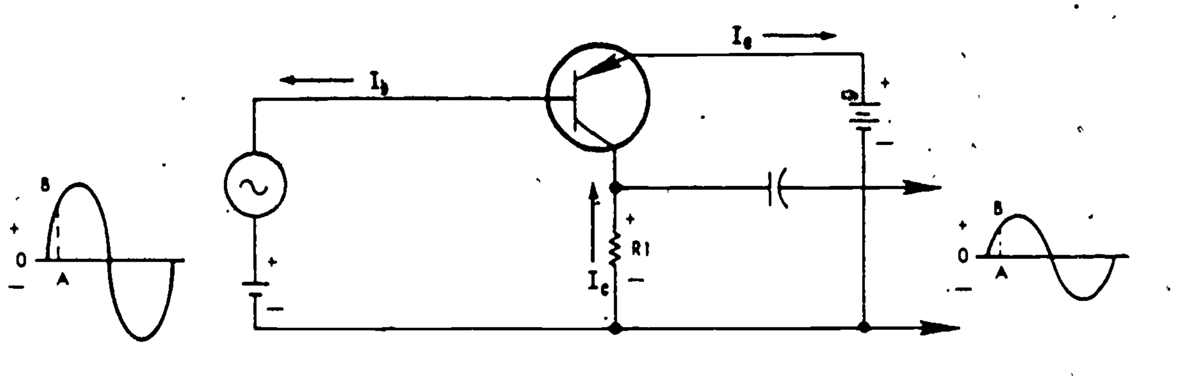


Figure 115. Common-collector (CC) amplifier.

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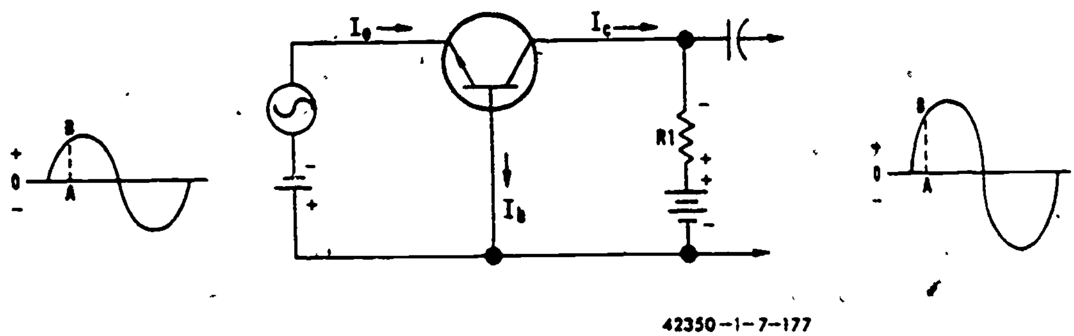

Figure 116. Common-base (CB) amplifier.

collector. The input signal is applied to the emitter terminal; the voltage waveforms represent the input and output voltages. The resistor R1 represents the load resistance of the circuit. The output signal is coupled out of the circuit by the coupling capacitor.

19-28. Now, follow the signal through the circuit. As the input voltage becomes more positive, represented by line AB, it opposes the bias voltage. This results in less current flow through the transistor. If there is less current flow through the transistor, there must be less current flow through the load resistor. As a result, the potential at the top of R1 rises. This produces an output voltage represented by line AB on the output waveform. Continuing through this analysis, you should find that there is no phase inversion through a CB amplifier. This particular type of amplifier is sometimes referred to as a grounded-base amplifier, and has an amplification capability of greater than one.

19-29. **Triggered circuits.** A triggered circuit is one in which an externally applied signal causes a rapid change in the operating state of the circuit. Once the applied trigger pulse has started the change, the circuit uses its own power to complete the changeover. This changeover operation is known as trigger action. Triggered circuits operate in a stable, monostable, or bistable modes of operation. These circuits, all variations of multivibrators, use different circuit values in various applications. After studying these explanations you should be able to readily transfer your knowledge to any similar circuit.

19-30. *Astable multivibrator.* The astable multivibrator, illustrated in figure 117, is a two-stage oscillator in which one stage conducts while the other is cut off until such a point is reached that the stages reverse their conditions. That is, the stage that has been conducting cuts off and other stages start to conduct. This oscillation continues and is used to produce a square-wave output. The multivibrator shown in figure 117 is connected as a collector-coupled circuit with the collector of each transistor connected to the base of the opposite transistor. There is a capacitor-resistor network in each coupling line. This type of circuit is also known as a free-running multivibrator. However, in certain applications, trig-

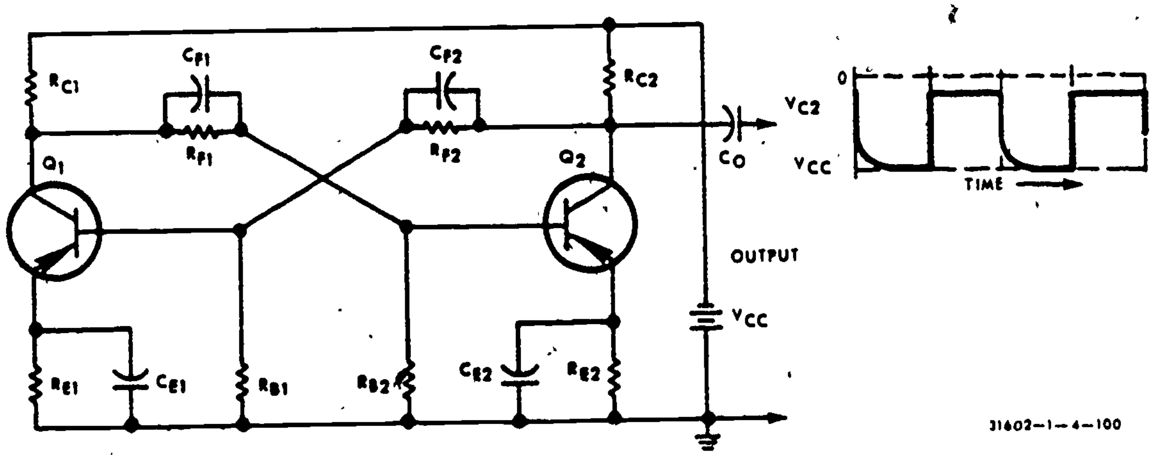

Figure 117. Astable multivibrator.

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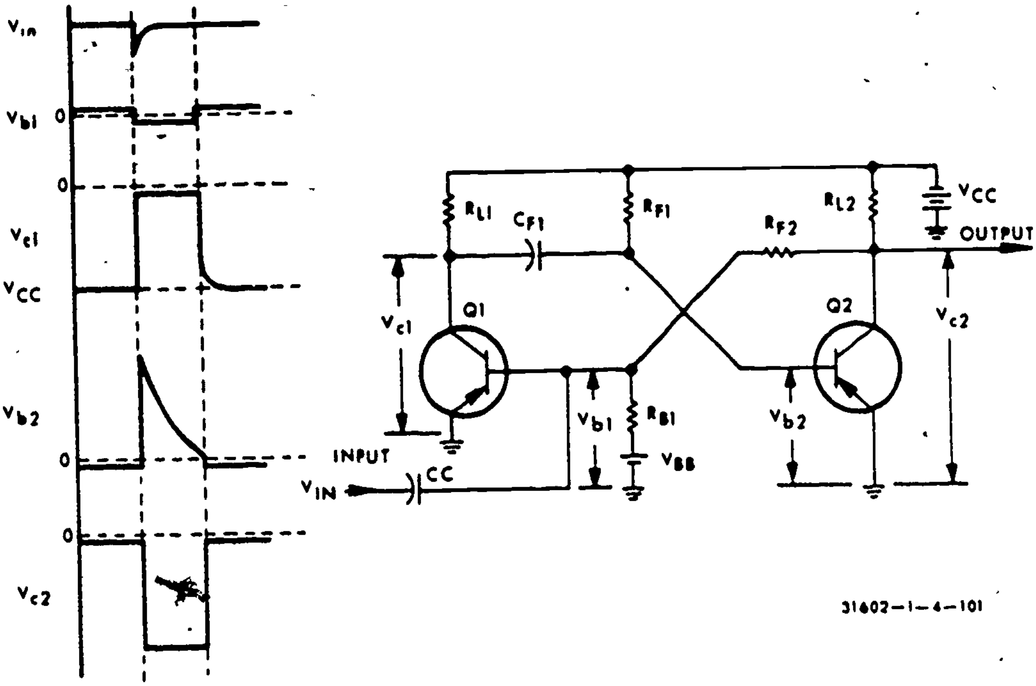

Figure 118. Monostable multivibrator.

gering pulses may be used to synchronize the astable multivibrator to another pulse-producing operation.

19-31. Follow the diagram of figure 117 as we explain the operation. To begin with, assume that Q_1 is conducting very heavily as compared to Q_2. Much more current is flowing in the base circuit of Q_1 than in the base circuit of Q_2. The collector current of Q_1 increases, causing the voltage at the junction of R_{C1} and R_{F1} to become more positive. This action places an even more positive bias on the base of Q_2 and cuts that transistor off completely. Keep in mind that these are PNP transistors, and for heavy current flow, the base must be negative with respect to the emitter. As Q_2 is cut off, the voltage at the junction of R_{C2} and R_{F2} becomes more negative. This negative voltage is applied to the base of Q_1. Transistor Q_1 is then driven to saturation. Saturation means that Q_1 is carrying all of the current possible under the voltage conditions applied to its collector and emitter with the maximum negative voltage applied to its base. At the time that Q_1 is saturated, the voltage drop across R_{C1} is maximum. This means that at this time, the potential at the junction of R_{C1} and R_{F1} becomes less negative. At the same time Q_2 is cut off, and the voltage at the junction of R_{C2} and R_{F2} becomes more negative.

19-32. All this action happens so quickly that capacitor C_{F1} does not get a chance to discharge. Therefore, the increased positive voltage that appears on the base of Q_2 is dropped across R_{B2}. The conditions remain practically static for the period of time it takes for C_{F1} to discharge. The base of Q_2 is going through a voltage change due to C_{F1} discharging.

19-33. When C_{F1} is practically discharged, the bias on the base of Q_2 is such that Q_2 begins conducting. As the current flow through Q_2 increases, the voltage at the junction of R_{C2} and R_{F2} becomes less negative. This voltage change is applied to the base of Q_1 and causes it to conduct less. As Q_1 conducts less, the voltage at its collector becomes more negative. This voltage change is applied to the base of Q_2. Transistor Q_2 is driven into heavier conduction. All this action continues until Q_2 is driven into saturation and Q_1 is cut off.

19-34. Again, the action was so rapid that C_{F2} did not have time to discharge. All of the circuit conditions again remain static except for C_{F2} discharging and changing the voltage applied to the base of Q_1. When C_{F2} is nearly discharged, Q_1 once again begins to conduct. This brings us back to the starting point. The frequency of oscillation is mainly dependent on the time constant of the resistor-capacitor combination (R_{F1}–C_{F1}, R_{F1}–C_{F2}) in each of the two crossovers from collector to base. Capacitors C_{E1} and C_{E2} are used as AC bypass units. Resistors R_{E1} and R_{E2} are used as swamping resistors. A *swamping resistor* reduces the effects of variations in emitter-to-base junction resistance caused

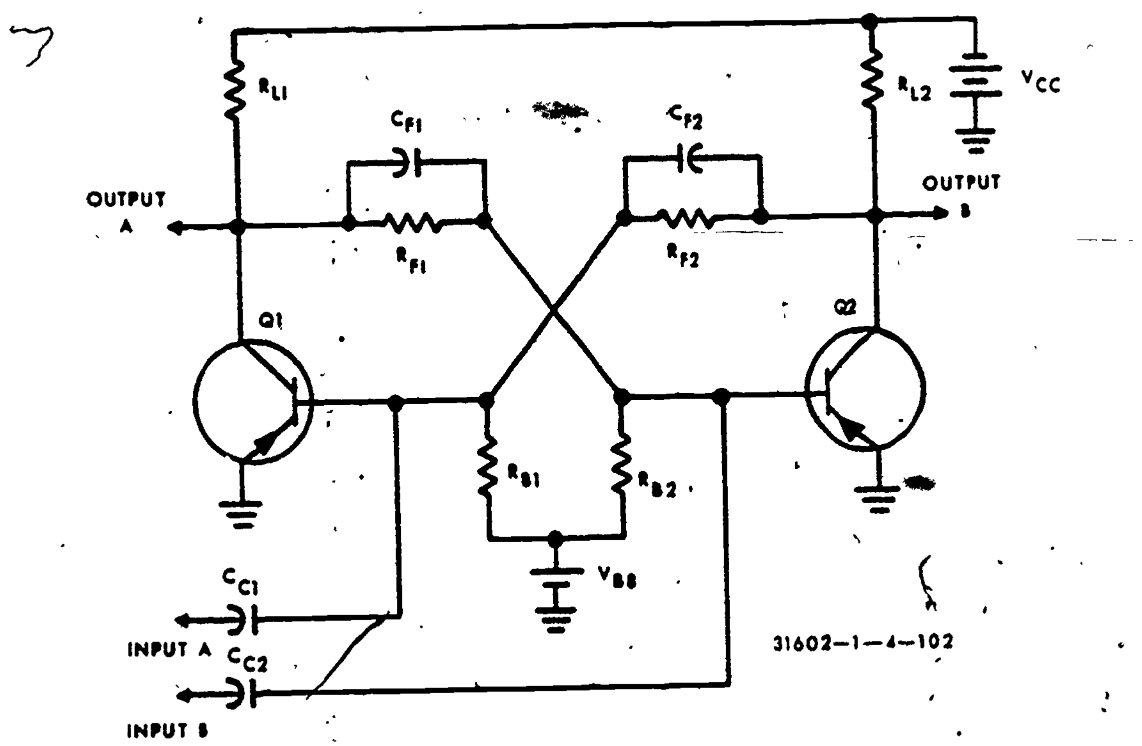

Figure 119. Bistable multivibrator.

by variations in temperature; thus, it reduces the possibility of excessive current through the transistor. Swamping resistors are placed in the emitter lead circuit. Review this explanation, and study figure 117 until you are reasonably sure you know how an astable multivibrator operates. Once you have mastered this multivibrator, the others will be easy to understand, since they are variations of the astable multivibrator. The next logical multivibrator to study is known as the monostable multivibrator.

19-35. *Monostable multivibrator.* The major difference between the astable (free-running) and the monostable multivibrator is the bias arrangement. In the astable unit the base-to-emitter junction is forward biased and starts oscillating as soon as DC power is applied. The monostable circuit, when power is applied, stabilizes with one stage cut off and the other stage at saturation. It remains in this condition until a trigger pulse is applied. The trigger pulse causes the transistors to switch states for a short time, as determined by the circuit values, and then return to their initial conditions. This type of multivibrator may also be referred to as one-shot, single-swing, or single-shot multivibrator. The monostable multivibrator, after a trigger pulse flips its operating state, flips itself back to its initial operating condition. Study figure 118 as you follow the explanation of the operation of a monostable multivibrator.

19-36. The battery V_{CC} supplies the voltage to the collectors of both Q_1 and Q_2. It also supplies the forward bias for Q_2. When thinking of biases, keep in mind that Q_1 and Q_2 are PNP type transistors. Therefore, VCC furnishes a forward bias through R_{F1} to the base of Q_2. The forward bias of V_{CC} causes Q_2 to be in a state of saturation while the reverse bias provided by V_{BB} holds Q_1 at cutoff. As we follow through the operation of figure 118, the various voltages developed in the circuit are shown by the graph at the left side of the figure, and in parentheses in the text.

19-37. The trigger pulse, shown as V_{in} in the graph, is a negative going pulse. It is applied to the base of Q_1 through CC. As the base of Q_1 is driven in a negative direction (V_{b1}) by the trigger pulse, conduction occurs through the transistor (from the collector to the emitter). Current flow through R_{L1} causes a voltage drop across it. Thus the collector of Q_1 becomes less negative (V_{c1}). This voltage change (V_{b2}) is reflected through C_{F1} to the base of Q_2. The forward-bias voltage on the base is decreased. Therefore, Q_2 conducts less, and the voltage on its collector goes negative (V_{c2}). This negative-going voltage is applied to the base of Q_1 and drives Q_1 into heavy conduction. The result is that Q_1 is driven into saturation and Q_2 is biased to cutoff. This switching action is so rapid that C_{F1} has not had time to discharge.

19-38. As C_{F1}' discharges through R_{F1} and Q1, the transistors remain stable in their switched positions. When C_{F1} is almost discharged, the voltage on the base of Q_2 has dropped (gone negative) enough to allow Q_2 to start conducting again. The positive-going voltage at the collector of Q_2 drives the base of Q_1 positive. This action causes Q_1 to conduct less. The collector of Q_1 goes negative as less current flows through R_{L1}. This negative-going voltage is applied to the base Q_2; thus, Q_2 is driven into saturation and Q_1 is driven to cutoff. The vibrator has returned to its monostable condition.

19-39. This stable condition remains until another trigger pulse is applied. The output can be taken from the collector of Q_1 as well as from Q_2. However, the output taken from Q_1 would be 180° out of phase with the output of Q_2. The output waveform is almost a square wave. The duration of the output or triggered pulse is determined primarily by the values, or time constant, of R_{F1} and C_{F1}.

19-40. *Bistable multivibrator.* A bistable multivibrator is stable with either of its transistors saturated. In other words, it *remains* in either mode of operation. The conventional bistable multivibrator is also known as an Eccles-Jordan trigger circuit or as a saturating flip-flop. It is used in computing and wave-generating circuits. Since it is controllable, its outputs can be made to represent 0 and 1 or false and true signals. Study figure 119 and follow it through during the explanation of the bistable multivibrator operation. Since the particular circuit of figure 119 shows PNP type transistors, any effective trigger pulse must be a negative-going voltage.

19-41. When power is first applied to this circuit, either transistor may go into saturation. To make the circuit predictable, a reset line is usually tied into the circuit to cause one particular transistor to go into saturation when power is applied. The resistors R_{L1}–R_{F1}–R_{B2}, and R_{L2}–R_{F2}–R_{B1} form voltage-divider networks that aid in holding the transistors in a stable state.

19-42. The application of either a negative trigger pulse to the base of the nonconducting transistor or a positive pulse to the base of the saturated transistor switches the conducting state of the circuit. The trigger pulses are applied through C_{C1} and C_{C2} to transistors Q_1 and Q_2 respectively. For the purposes of this explanation, assume that transistor Q_1 is cut off while Q_2 is conducting. A negative trigger pulse at input A drives the base of Q_1 in a negative direction. Transistor Q_1 starts conducting and so develops a positive-going voltage at its collector. This positive-going voltage is coupled to the base of Q_2 by R_{F1} and C_{F1}. The change of bias on the base of Q_2 causes it to conduct less. Since Q_2 conducts less, its collector voltage goes more negative. This negative-going voltage is coupled to the base of Q_1 through C_{F2} and R_{F2}. The increased negative bias on the base of Q_1 causes it to go into heavier conduction. Transistor Q_1 conducts more heavily, driving the base of Q_2 even more positive. The final result of all of this is that Q_1 is driven to saturation while Q_2

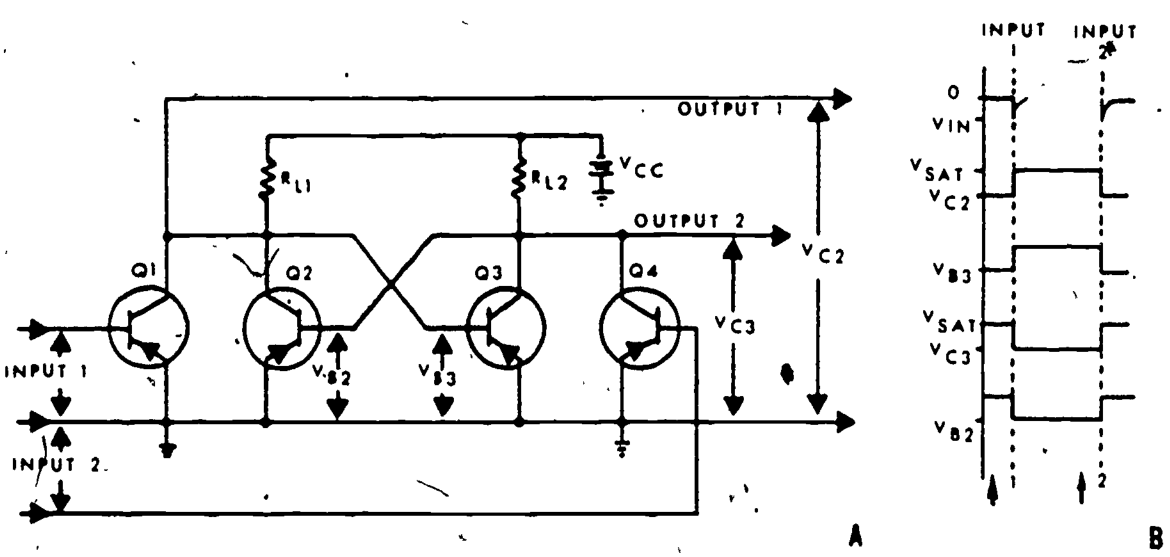

Figure 120. Direct-coupled bistable multivibrator.

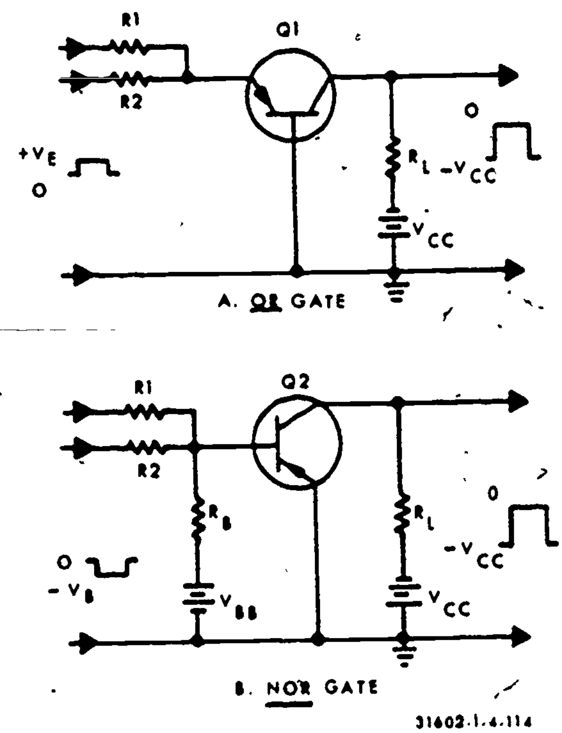

Figure 121. OR and NOR gating circuits.

is biased completely off. Actually, this transition (switching) period is very short.

19-43. With Q_1 at cutoff and Q_2 saturated, a negative trigger pulse applied to input B indicates the chain of events that drives Q_2 into cutoff and Q_1 into saturation. The output waveform very closely resembles a square wave when continuous triggering is applied.

19-44. The *direct-coupled bistable multivibrator,* as illustrated in figure 120, is also known as a binary or "count-by-two" circuit. It is used in computing and counting applications. The transistors Q_1 and Q_4 are not part of the basic flip-flop, but are used to amplify the input control signal. The loads for Q_2 and Q_3 (the bistable multivibrator transistors) are R_{L1} and R_{L2} respectively. The load resistors also serve as the base input resistance of the other transistor. That is, R_{L1} is also the base input resistance for Q_3, and R_{L2} is also the base input resistance for Q_2.

19-45. In the explanation of the direct-coupled bistable multivibrator, follow the circuit of figure 120, and the voltage-versus-time graph in 120. Let's start by assuming that transistor Q_2 is cut off and Q_3 is conducting. While this stable condition exists, the base of Q_3 is at a high-negative potential and the base of Q_2 is almost at ground (positive) potential. The reason for this is that the base of each transistor is coupled directly to the collector of the other transistor. The transistor that is conducting heavily (saturated) causes a positive potential to be applied to the base of the other transistor. The transistor that is cut off (Q_2) causes a negative bias equal to battery voltage to be applied to the base of the conducting transistor Q_3. Now assume that a negative-going trigger pulse (V_{IN}) is applied to the base of Q_1. Transistor Q_1 conducts and effectively grounds the collector of Q_2 (V_{C2}). At the same time, it grounds the base of Q_3 (V_{B3}) by direct coupling. All of this initiates a chain reaction which causes Q_3 to be cut off and Q_2 to be driven into saturation. The voltages shown vertically under the input 1 line of the graph are the stable conditions following the pulse on input 1.

19-46. The new stable condition exists until a negative-going pulse is applied to input line 2. This time Q_4 effectively grounds the collector of Q_3 and the base of Q_2, causing a switching action between the transistors. The voltage changes are shown under the input 2 section of the voltage waveform diagram. This shows that the voltages are brought back to their initial conditions.

19-47. By connecting output 1 and output 2 to the inputs of another multivibrator, and its outputs to another and so on, a chain of these can be constructed to form a computing device known as a binary-counter string. Depending on

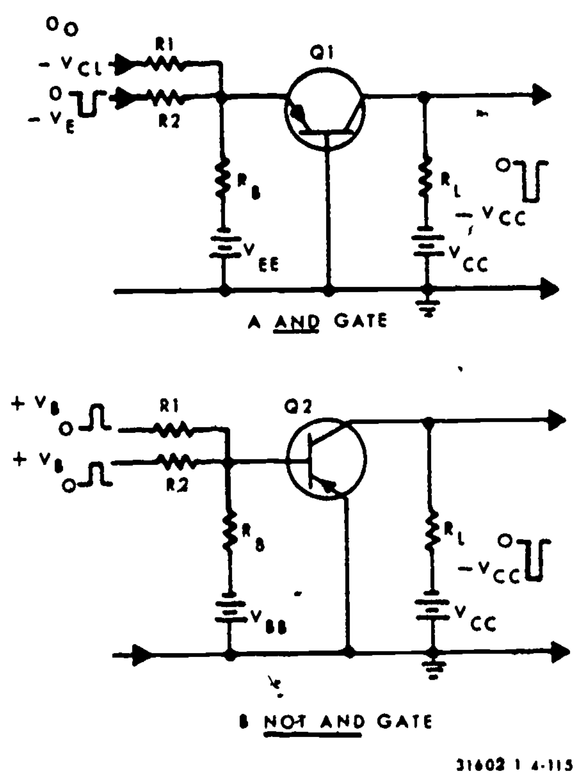

Figure 122. AND and NOT AND gating circuits.

how one multivibrator is connected to the next, the chain can be made to function as a counter or a shift register. The information on triggered circuits presented in this section has, of course, only scratched the surface of the subject. We have presented it as a beginning from which you can progress to an understanding of the many other types and designs of transistorized triggered circuits.

19-48. *Gating circuits.* These circuits are used extensively in computer circuits. They function as switches by making use of open or short circuits between the emitter and collector of transistors. Transistors used in gating circuits may be connected in series, parallel, or series-parallel. A large variety of functions may be established, depending on the manner in which the transistors are connected.

19-49. Included in the overall category of gates are the AND, OR, NOT AND, and NOT OR (NOR) circuits. The NOT refers to a circuit design that provides pulse polarity inversion. For instance, an inverted output from an AND provides a NOT AND gate. Since these circuits have the ability to evaluate input conditions and respond with a predetermined output, they are also referred to as logic circuits. The circuits that will be explained here are typical. You may find slight variations in actual circuits. Since there are so many variations possible in designing any particular gate or combination of gates, a general understanding is preferable at this time. Having gained a general knowledge of gating circuits, you will be better equipped for specific circuits that you may find in subsequent chapters of this course.

19-50. *OR and NOR gates.* An OR gate has more than one input but only one output. Simple methods of obtaining OR and NOR gates are illustrated in figure 121. We will use this figure in the following explanations of OR and NOR gates.

19-51. A positive trigger pulse applied to either of the OR gate inputs will cause transistor Q_1 to conduct. This will cause the collector voltage to go from a high-negative potential to almost zero or ground potential. The input and output voltage waveforms are illustrated in section A of figure 121. The input signal is applied to the emitter. Although only two input lines are shown, several may be used. Remember, only one input pulse is required to trigger an OR gate. You should recognize this configuration as a common base with emitter input.

19-52. The NOR gate uses base signal input. The output is taken between the collector and ground. This is a typical common emitter configuration. The base is biased off by the action of V_{BB} and R_B. A signal input through either R_1 or R_2 will reduce the reverse bias enough to cause Q_2 to conduct if the input signal is negative. When Q_2 conducts it acts as a short between the top of R_L and ground. The result is phase inversion of the signal. This signal output will last only as long as the input pulse.

19-53. The OR and NOR gates illustrated in figure 121 are by no means the only circuits possible. But if you understand the ones presented, you can readily understand simple circuit variations.

19-54. *AND and NOT AND gates.* The AND gate requires two or more simultaneous signal inputs of the proper polarity to trigger the gate and causes an in-phase output. The NOT AND gate requires two or more signals of the proper polarity to trigger the gate and causes an inverted-phase output signal. Study figure 122 and refer to it as you read the following description.

19-55. The emitter to base bias of the AND gate is such that Q_1 is conducting when no signal is applied. The circuit design is such that a single input pulse will not trigger the circuit. It takes two pulses, applied concurrently, to overcome the forward bias. The transistor is then effectively cut off. The transistor will be held at cutoff as long as both signals are applied. Since the type of circuit illustrated in section A of figure 122 is of the common base with emitter input, there is no phase inversion. The representative waveforms are shown in figure 122. Removal of either input signal will allow the transistor to go back into conduction.

19-56. The NOT AND gate does show phase inversion between the input signals and the output signal. Here again the transistor is forward biased. Notice that this time the transistor is used in a common emitter with a base input type of circuit. The waveforms for the NOT AND gate are illustrated in section B of figure 122. The AND or NOT AND gate is also known as a coincidence type gate.

19-57. This concludes Chapter 7. Answer the questions at the end. If for any reason you are not confident in your ability to understand or discuss electronic circuitry, reread the chapter. The material covered in this chapter is interspersed throughout Volumes 2 and 3 as application of electronics in the equipment an electrician maintains. Anytime the application cannot be understood, refer back to this chapter for the basic operation.

Application of Electron Tubes

THIS CHAPTER will cover the electron tube and its circuitry. Electron tubes and related circuitry are presented, with emphasis on operation and applications. Operation is the required working circuitry for the electron tube which allows it to perform as a rectifier, an amplifier, or a regulator. The applications are the specific functions of electronic power supplies and multistage amplifiers including the use of the CRT.

2. At the conclusion of this chapter, you should be able to understand and discuss the basic operation of rectification, amplification, and regulation of electronic circuits.

20. Electron Tubes and Circuitry

20-1. The ability of electron tubes to control relatively large amounts of power upon the receipt of minute control signals allows them to have a wide variety of applications in aircraft electrical systems. Although you learned the principles of operation of the electron tube in school, let us begin this discussion with a brief review of electron tubes in general.

20-2. **Electron Tube Parts.** The basic parts of an electron tube are the envelope, the filament, and the plate.

20-3. *Envelope*. This unit may be made of metal or glass and in a wide range of sizes and shapes. In vacuum tubes, the envelope is completely evacuated; for others, it is filled with an inert gas. Tubes having metal envelopes are intended for installations that must be shielded from magnetic interference, and they are not normally used where high voltages are present.

20-4. *Filament*. The type of filament used in a tube depends on the use for which the tube is intended. Tungsten, in combination with thorium, is used for many tube filaments; pure tungsten is used mostly in high-power tubes.

20-5. Tubes used in lower voltage circuits may have an oxide-coated filament. To obtain such a filament, nickel or platinum alloys are coated with alkaline-earth oxides of metals such as barium, strontium, or calcium. Oxides work well only in tubes that are subjected to less than 500 volts, because higher voltages will tear away the coating.

20-6. The cathode, as you recall, supplies the electrons necessary for operation of the tube. When the cathode is heated to the proper emission temperature, electrons are driven from its surface. Cathodes are classified according to the method used for applying heat, which may be directly or indirectly.

20-7. A directly heated cathode is one in which the filament is also the cathode. That is, the heated conducting wire gives off all the necessary electrons. Since most directly heated oxide-coated filaments require comparatively little power, they are often used in tubes designed to operate on battery power or in portable equipment.

20-8. In the indirect unit, the cathode surrounds the heater filament (the source of heat), and the heat is conveyed to the cathode by conduction. The indirect heater is most commonly used in tubes that operate on alternating current.

20-9. *Plate*. The purpose of the plate is to receive the electrons emitted by the cathode. The plate is usually made of nickel, carbon, or molybdenum. It is designed to radiate heat and remain at a fairly low temperature so that it absorbs rather than emits electrons.

20-10. **Electron Emission.** The operation of all electron tubes depends upon an available supply of electrons. There are various ways of emission by which this supply can be obtained. Let us turn our attention to the thermionic-emission method as a starter.

20-11. *Thermionic emission*. Thermionic emission is the process of liberating electrons from a metallic emitter by applying heat. From earlier discussions you recall that all substances contain electrons in random motion. When heat is added, energy is added to that already possessed by the

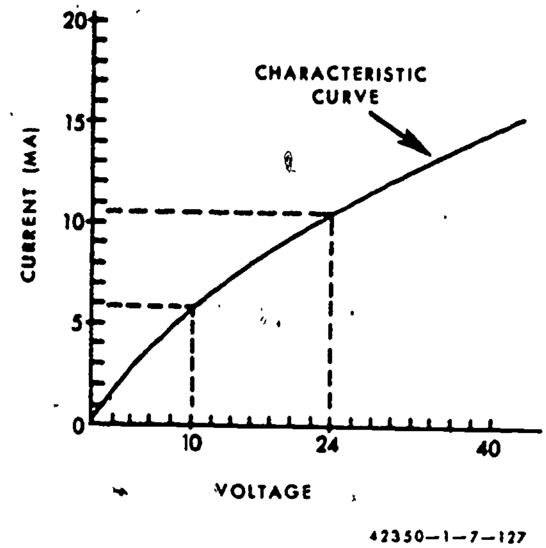

Figure 123. Characteristic curve.

moving electrons, and their movement is accelerated.

20-12. *Secondary emission.* In this type of emission, electrons are detached from a body that is being pelted by electrons that have been emitted from a primary source. Whenever a stream of high-velocity electrons strikes a metallic substance, they impart enough energy to the electrons within the metal to enable them, in turn, to break through the potential barrier.

20-13. *Photoelectric emission.* Light is an electromagnetic wave or a form of energy. Electron emission takes place when light strikes a photosensitive metal; the light energy frees electrons from the metal in direct proportion to the intensity of the light.

20-14. *Cold-cathode emission.* In emission such as this, electrons are pulled from the cathode substances by a strong electrical attracting force. The cold cathode method is not commonly used because of the high voltages necessary to attract electrons.

20-15. **Space Charge.** Once liberated, the electrons travel about in space. In electron tubes the term "space charge" is restricted to the charges that give rise to an accumulative effect near the cathode.

20-16. When heat is applied to the cathode, the electrons move with increased velocity until they break through the surface of the material. Electrons have little energy left after they leave the cathode because most of it is lost when they pass through the potential barrier. The emission itself is haphazard, and the electrons wander in space in different directions. You already know that like charges repel one another; therefore, the electrons that journey the farthest tend to repel the ones that are closer to the cathode. These, in turn, repel the electrons that are just leaving the cathode surface. The net result is that near the cathode there is a cloud of electrons.

20-17. The space charge continues to build up until a point of critical density is reached. At that time the charge (or cloud) can no longer receive an electron unless it forces one to return to the cathode. When this happens, the space charge is at the *emission saturation point.*

20-18. This condition varies with the cathode temperature ranges. An increase in cathode temperature raises the velocity of the emitted electrons; these new ones then enter the space charge and make it more dense until the field strength can offset their increased velocity. At this point a new level of emission saturation is reached. You can see, therefore, how the space charge enables us to control the emission of electrons. A second electrostatic field exists between the space charge and the plate. Since electrons are negative, the plate which is to absorb them must be positive in relation to the cathode. However, the space charge between the two units tends to retard the emitted electrons. Knowing these conditions, you can conclude that the attracting force of the positive plate acts on the electrons in the space charge rather than directly on those that are leaving the cathode. Thus, the plate has either some excess positive charges or a deficiency of electrons. Actually, the electrons move from the cathode to the space charge and from there to the plate without changing the density of the space charge. But how? Each time an electron is absorbed by the plate, another one leaves the cathode to maintain the emission saturation. Because of this action, the directed movement of electrons can be described as the flow of plate current between the cathode and the plate, and then through the rest of the system.

20-19. Just as the temperature of the cathode affects the number of electrons being emitted, so does the *positive plate voltage* control the number of electrons entering the plate from the space charge. For a given value of plate voltage and a constant cathode temperature, a fixed number of electrons are drawn in from the space charge. This yields a current which is measured in amperes (or milliamperes). Any change in the plate voltage varies the rate of electron flow and the resulting plate current. When the voltage is high, all of the electrons passing from the cathode enter the space charge and go directly to the plate. This sets up a condition wherein the plate and the emission currents are equal. If there were no space charge, a very low voltage on the plate would result in extremely high values of

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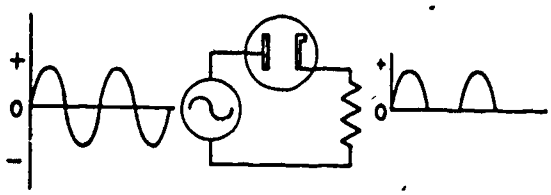


Figure 124. Diode operation as a half-wave rectifier.

current and a short emitter life. To prevent this, the cathodes in most tubes are designed to emit a surplus of electrons. When the plate voltage is low, the emitted electrons nearest the cathode are forced back to it by the accumulation of electrons that are a little farther away from the cathode. At the same time, the plate attracts only those electrons that are nearest to it. For intermediate values of plate potential, the space charge in the vicinity of the cathode is reduced by the attraction of more electrons to the positively charged plate. From this, you can see that particular manufacturing features based on the use of space charge gives tubes definite operating characteristics.

20-20. **Vacuum Tubes.** To begin, let us explain certain characteristics that apply to vacuum tubes.

20-21. *Characteristics.* In a vacuum tube, as previously stated, a definite relationship exists between the plate voltage and the plate current. There is also a relationship between the cathode temperature and electron emission, which, as you have learned, establishes the characteristics of a particular tube. These characteristics may be quite different from those of a tube designed for another purpose; you can clearly determine what they are by graphs known as characteristics curves. For simplicity, you can regard these curves as charts of cause and effect plotted within the boundaries of two reference lines which serve as scales to indicate the various units of measurement (volts, ohms, amperes).

20-22. Figure 123 illustrates what has just been said. The vertical reference line indicates the amount of plate current in terms of milliamperes (ma), and the horizontal one denotes the plate voltage. At the zero point, the plate current is cut off. By placing a 10-volt potential on the plate, a plate current of 5.6 ma is obtained. This information is supplied by the tube manufacturer in the form of the characteristic curve. As revealed in the figure, you construct a vertical line from the 10-volt marker on the horizontal axis until it intersects the curve; then draw a horizontal line from the point of intersection to the vertical axis. A step-up of plate voltage from 10 to 24 volts changes the plate current from 5.6 ma to 10.6 ma, as shown by the second set of vertical and horizontal lines. By using the same curve, you can determine plate voltage values for known values of current.

20-23. So far, the tubes that have been discussed contain only two elements, a plate and a cathode. Such units are known as diodes. As more elements (electrodes) are added, the tubes are known successively as triodes, tetrodes, pentodes, and so on down the line of Greek prefixes. The diode, of course, is the first and, therefore, the simplest in construction.

20-24. *Diode tubes.* One of the most common uses of the diode tube is to rectify, which means, as you know, to convert AC to DC. To see how this is done, turn your attention to figure 124. Observe that when the AC power supply is on the positive alternation of the sine wave (shown at the left) the plate has a positive potential applied and the cathode a negative one. From the previous discussion, you know that such conditions are necessary for the tube to operate. As the plate voltage increases, so does the plate current. At the highest point on the AC sine wave, the plate has the greatest potential and current. The current drops to zero with the decrease in the positive alternation because of the loss of the attracting force in the plate. On the negative alternation nothing happens, for in this state the polarities do not lend themselves to conduction within the tube. Then, there is another positive alternation that reestablishes the positive plate and negative cathode, and current flows again. In effect the negative alternation has been eliminated. A diode tube used for this purpose is called a half-wave rectifier.

20-25. Diode tubes may be combined to provide full-wave rectification, or a dual-diode tube may be used.

20-26. *Dual diodes.* The dual diode is a sin-

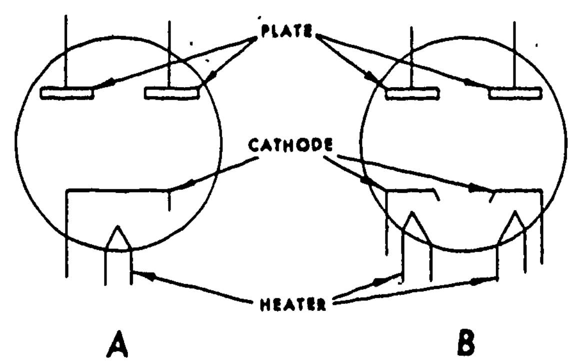
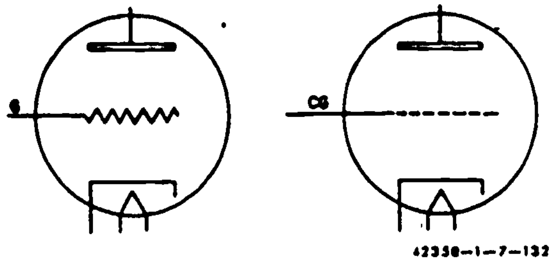


Figure 125. Dual-diode schematics.



G. GRID CG. CONTROL GRID

Figure 126. Triode schematics.

gle tube containing two sections, each being the equivalent of one diode.

20-27. Dual diodes (A and B, fig. 125) contain two plates, though they may have one or two cathodes and heater filaments. This depends upon the circuits for which the tubes are designed.

20-28. Remember that the simple diode conducts only when the plate is positive and the cathode is negative. The dual diode, on the other hand, has the proper polarities in one of its sections during each alternation of the power supply. First one section and then the other conducts the successive alternations. In this situation, as you would expect, the dual diode is a full-wave rectifier.

20-29. *Triode tubes.* In a triode, the cathode and the plate retain their functions as a source of electrons and a collector of electrons. In the space between them, and located closer to the cathode, is the control grid. This third element, as shown in figure 126, appears in schematics as either a zigzag or a dashed line, and it is distinguished from other grids by the capital letters "G" or "CG."

20-30. Briefly, the purpose of the control grid is to govern the movement of electrons between the cathode and the plate, thereby controlling the instantaneous plate current flowing through the tube. As previously mentioned, the plate voltage determines the number of electrons attached to it. What, then, is the electrical difference between the triode and the diode? Essentially, the diode changes AC to a pulsating DC. In the triode, a voltage on the grid can vary the plate current when the voltage applied to the plate is held constant.

20-31. The polarity and the amount of voltage on the diode plate results in a one-direction flow of pulsating plate current. In the triode, the applied DC voltage is obtained from a constant source like that from a dual diode. The effect of a positive plate voltage in a triode can be overcome by the application of the proper amount of negative voltage to the grid. (This plate voltage often runs as high as 5000 volts.) From what has been stated, you might be led to believe that the grid acts as a valve. Although the grid is often referred to as a valve, the term is not fully descriptive. Nevertheless, the valving action is important because it is the basis for many functions of a triode, especially its ability to deliver a stronger signal than it receives. This process is called amplification, and it will be discussed in detail in another section of this volume.

20-32. The triode is a thermionically heated electron tube in which a space charge is developed between the cathode and the grid, as shown in figure 127. (The small circles represent

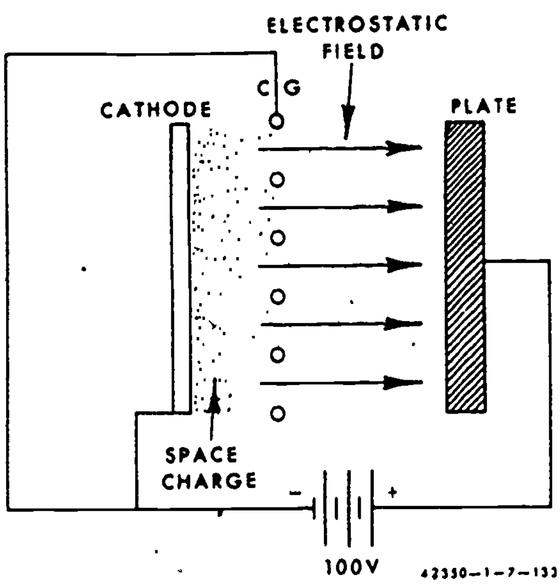


Figure 127. Triode tube with cathode and grid potential equal.

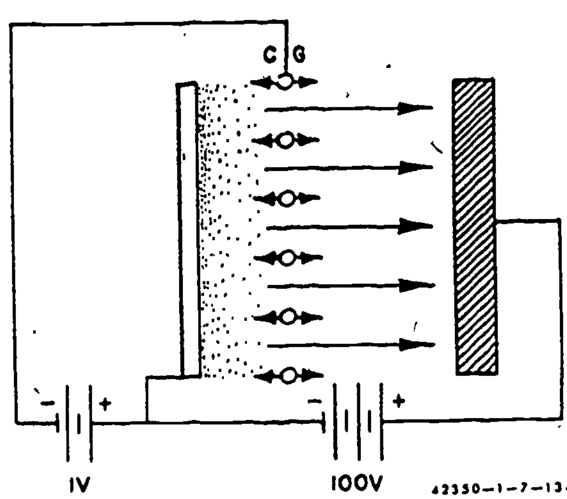


Figure 128. Negative grid with respect to cathode.

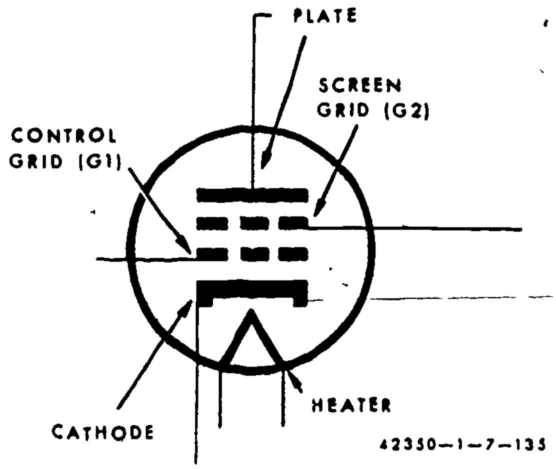


Figure 129. Schematic tube symbol for a tetrode.

the control grid, which is wound around the cathode.) When a positive voltage is applied to the plate, the electrostatic field that is formed (shown by the arrows) draws the electrons toward the plate. So far, the action of the triode differs little from that of the diode.

20-33. If a small battery or other source of a DC power supply is introduced into the assembly (see fig. 128), the grid can be made negative with respect to the cathode. With voltage applied to both the plate and the grid, two electrostatic fields are produced within the tube. One attracts electrons to the positively charged plate; the other (the field of the negatively charged grid side that faces the cathode) restores electrons to the space charge, and in this manner reduces the number of electrons that advance to the plate. The movement of electrons to the plate through the grid openings is controlled by the predominant electrostatic field.

20-34. The application of a positive voltage to the triode grid causes the electrons to be accelerated in their travel to the plate and results in an increase of plate current. When AC is applied to the grid, it becomes positive at one instant and negative the next. Thus, a variation in plate current occurs as the AC grid signal varies. The output current in the plate circuit will still be direct, but of fluctuating amplitude.

20-35. The change in plate current for a given signal voltage depends upon the tube and its purpose. The theoretical relations developed for a triode will apply equally well to tetrodes and pentodes. Therefore, it will be necessary to consider here only the effects of the additional

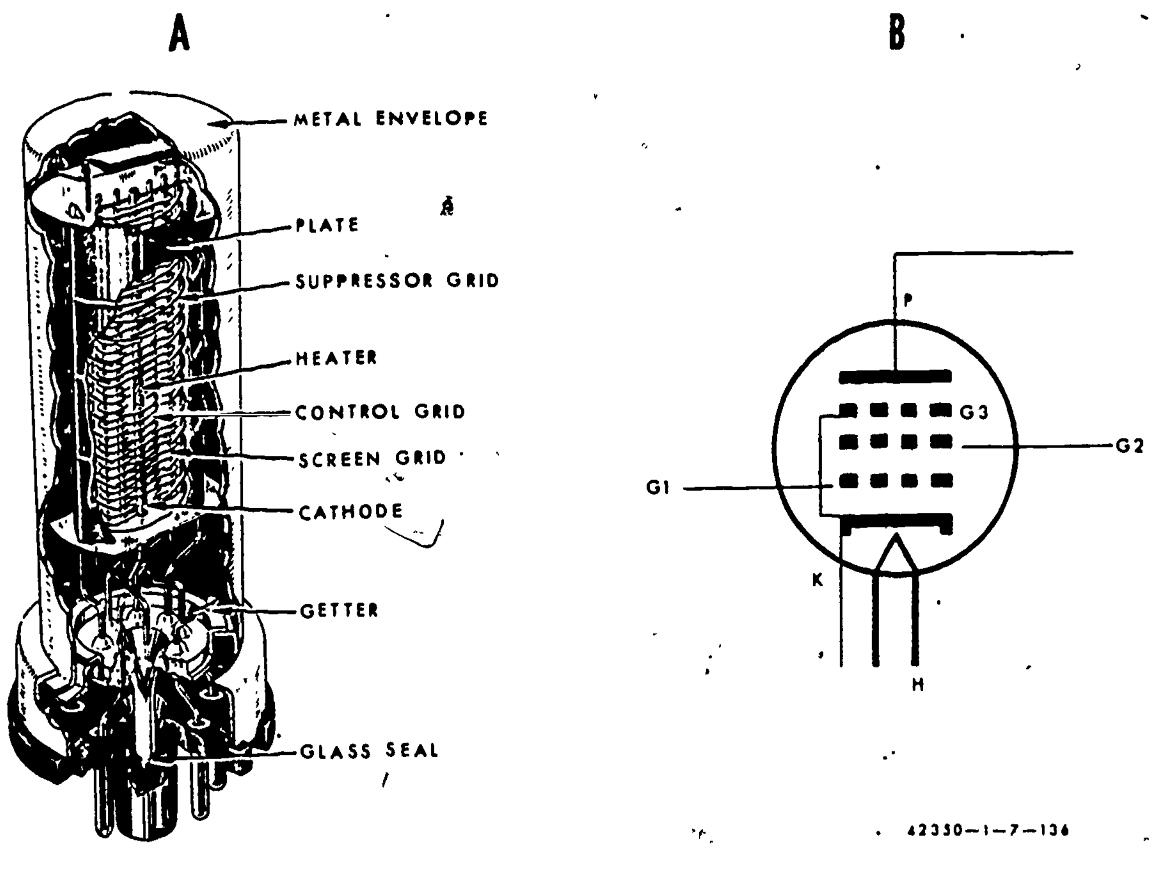


Figure 130. Physical construction and schematic symbol for metal type pentode.

electrodes as we study the current flow to the plate.

20-36. *Tetrode.* The tetrode tube contains all the electrodes of a triode and, in addition, a fourth electrode called the *screen grid.* The screen grid was added to the electron tube to decrease the capacitance between the control grid and the plate.

20-37. The construction of a tetrode is very similar to that of a triode, except for the *screen grid.* The screen grid is located between the control grid and plate, as shown in figure 129. The shape of the grids in tetrode tubes varies; however, the functioning of the electrodes is fundamentally the same regardless of shape.

20-38. *Pentode.* The pentode tube contains all of the electrodes of the tetrode and, in addition, a fifth electrode called the *suppressor grid.* The suppressor grid is placed between the plate and the screen grid to eliminate the effects of secondary emission.

20-39. Secondary emission effects restrict a tetrode to those amplifier circuits with high plate voltage. Removal of this limitation would permit the tube to have wider usage. This was made possible by the suppressor grid placed between the screen grid and plate. Thus, the pentode—with cathode, control grid, screen grid, suppressor grid, and plate—came into being.

20-40. The pentode is a 5-electrode electron tube. It contains an emitter, three grids, and a plate. The grid closest to the cathode is the control grid, G1; next is the screen grid, G2; and the third, located between the screen grid and the plate, is the new suppressor grid, G3. The pentode symbol is shown in figure 130. There are other kinds of tubes, however, in which the flow of current is through a relatively dense gas.

20-41. **Gas-Filled Tubes.** In tubes of this type, the gas is about one ten-thousandth as dense as air under normal atmospheric pressure. When an electron collides with a gas molecule, the energy imparted by the impact can cause the molecule (or atom) to lose or gain one or more electrons. The result is ionization. Any gas or vapor having no ions is practically a perfect insulator. If two electrodes are placed in such a medium, no current will flow between them. However, gases always have some residual ionization because of cosmic rays, radioactive materials in the walls of the container, and the action of light. If a potential is applied between two elements in such a gas, the ions migrate between them and give the effect of current flow. This is called the dark current because no visible light is associated with it. Its value is about 1 ma.

20-42. If the voltage on the electrodes is increased, the current starts to rise. At a certain point known as the threshold (usually about 2 ma), the current suddenly begins to go up without any increase in applied voltage. If there is enough resistance in the external circuit to prevent the current from rising quickly, the voltage immediately drops to a lower value and breakdown occurs. This abrupt change takes place as a result of the ionization of the gas by electron collision. The electrons released by the ionized gas join the stream and liberate other electrons. The process, then, is cumulative. Breakdown voltage is determined primarily by the type of gas, the materials used for the electrodes, and their size and spacing. Once ionization takes place, the current can rise to 50 ma or more with little change in the voltage applied. If the voltage is raised, the current increases and the cathode is heated by the bombardment of the ions that strike it. When the cathode gets hot enough, thermionic emission results. This emission reduces the voltage loss in the tube, which, in turn, causes more current to flow and increases the rate of emission and ionization. This cumulative action involves a sudden decrease in the voltage loss across the tube and a current rise to an extremely high value. Unless the tube is specifically designed to operate in this manner, it can be destroyed by the heavy current flow.

20-43. The condition just described is basic to the formation of an arc; therefore, tubes that operate at these high currents are called arc tubes. For currents up to 50 ma, the unit usually is small and is termed a glow tube because of the colored light it emits. An example of such a tube is the familiar neon light.

20-44. In the gas-filled tubes, you will find the diode type, just as you do in vacuum tubes.

20-45. *Gas diodes.* A unit that contains two electrodes in a gaseous medium (helium, neon, mercury vapor) is called a gas diode; these elements, as in vacuum tubes, are called the plate and the cathode. The cathode in a gas diode can be an electrode similar to the plate in a vacuum tube, or it may be a thermionic emitter. The former design is known as a cold cathode and the other as a hot cathode.

20-46. The gas diodes, like the vacuum ones, are also used as rectifiers. However, gas rectifiers are able to pass much greater currents than high-vacuum tubes because of the ionization of the gas within the envelope. The ions make it unnecessary to rely on the electrons produced by the filament, which is used merely to start ionization of the gas. Actually, the filament heat vaporizes a small amount of mercury in the mercury vapor tubes. Because of their low voltage loss,

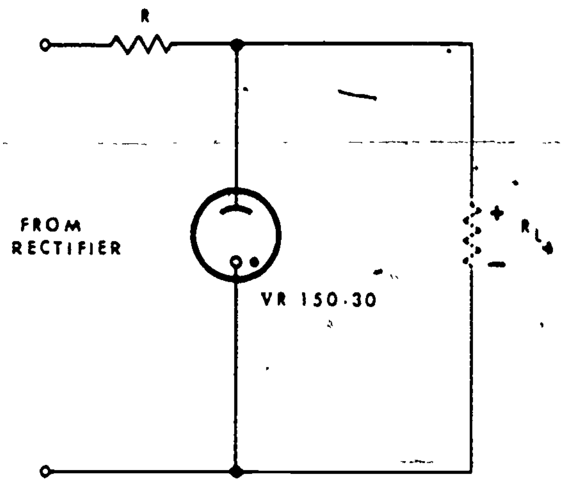


Figure 131. VR tube circuit.

they have a high efficiency in power rectification, which, in some instances, easily approaches 99 percent. Since the loss does not vary with a changing load, as is the case in vacuum types, the gas tube gives better voltage regulation.

20-47. Voltage regulators are circuits designed to maintain the output voltage of a power source at a constant, predetermined level, even though the input voltage or the load varies.

20-48. *VR tubes.* As you recall from your study of gas tubes, a VR tube has a constant voltage drop across it if the current is held within limits. In the circuit shown in figure 131, the output voltage is regulated by the VR 150-30 tube at 150 volts as long as the current through the tube does not exceed 30 ma. A minimum current of 5 ma must be maintained to keep the tube from extinguishing. In other words, the current through the tube must be maintained between 5 ma and 30 ma to keep the output voltage regulated.

20-49. By proper selection of limiting resistor R, the output voltage is maintained at 150 volts regardless of changes in input voltage from the rectifier or of changes in load. If the input voltage rises, more current flows through the VR tube and a greater voltage drop occurs across R. This greater voltage drop keeps the voltage across the load R_L constant. A decrease in input voltage causes a smaller voltage drop across R and so keeps the output voltage constant. A change in load is compensated by a change in current flowing through the VR tube. This, in turn, keeps the voltage drop across R constant and, therefore, maintains a constant output voltage.

20-50. One of the major disadvantages of VR tubes is their comparatively low-voltage rating. This disadvantage may be overcome by connecting several VR tubes in series as shown in figure 132. This circuit provides for three regulated voltages, which are 330 volts from A to ground, 180 volts from B to ground, and 75 volts from C to ground. Note that a limiting resistor, R, is used also in this circuit to keep the current flowing through the tubes between 5 ma and 30 ma.

20-51. In the previous section you learned how grid control is affected in vacuum tubes; now you will see how it works with gas tubes.

20-52. *Thyratrons.* The principle of grid control can be applied to almost any gas tube, but it is used specifically with cold cathode, hot cathode, and arc types of triodes and tetrodes. All are given the general name of thyratron.

20-53. With voltage on the grid, the voltage at which breakdown occurs can be regulated. The grid, which shields the plate surface before breakdown, is located close to the plate to prevent discharge. Then, should a discharge take place, it would be only in the unimportant dark-current range. In these tubes, the plate supply voltage exceeds the plate-cathode breakdown voltage, and the grid remains either zero or negative with respect to the cathode. Under these conditions there is no breakdown.

20-54. If the grid voltage is raised, there is breakdown between the grid and the cathode. This action causes all of the gas in the tube to be ionized, and the discharge continues with plate-cathode current flow. A resistance placed in series with the grid limits its current on break-

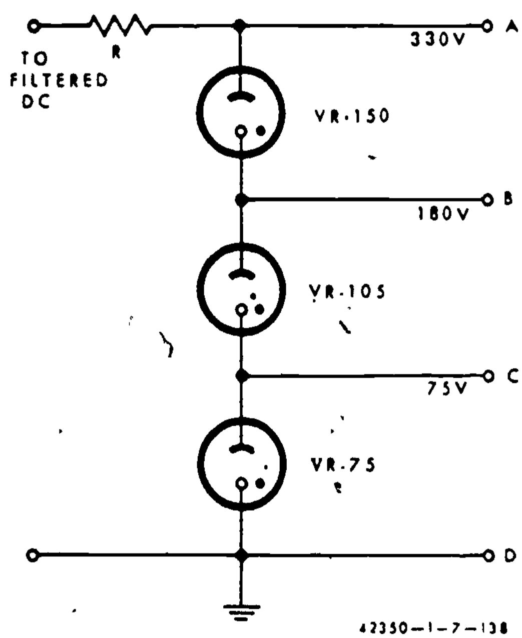


Figure 132. VR tubes in series.

down to a safe value. After breakdown the grid is unable to control the discharge. To reestablish grid control, the plate potential must be reduced until the cathode-plate discharge disappears.

20-55. In gas tubes, either hot- or cold-cathode emission can be used instead of directly heating the filament as with vacuum tubes, which function primarily through the thermionic method.

20-56. The next part of this section discusses the principles of operation of the cathode-ray tube, which is used in the oscilloscope, one of the most important items of test equipment you use.

20-57. **Cathode-Ray Tube (CRT).** This tube is the very heart of the oscilloscope. It is a large vacuum tube shaped like a funnel; that is, long, conical, and flared at one end. The small end fits into a socket and is equipped with the required number of contacts for the electrical controls. The large end of the tube serves as the screen. When this tube is installed in an oscilloscope, you see only the screen end because the barrel and socket base are hidden deep within the case of the scope.

20-58. If you were to slice the cathode-ray tube in half lengthwise, it would look something like the drawing in figure 133. The inside of the screen is painted or coated with a fluorescent substance (one which gives off light when struck by electrons) so that a visible indication may be obtained. *Willemite* is used for the coating of the screen because of the soft green light it emits when bombarded by electrons. Other fluorescent substances, such as cadmium tungstate or zinc sulphide, may be used for the same purpose. One of the principal factors determining the material chosen for the screen coating is the *persistency* of the material. The persistency of the screen coating determines how long a spot will remain visible after an electron has hit the screen. Most oscilloscopes use a screen of low persistency so that the image disappears soon after the electron beam has moved on.

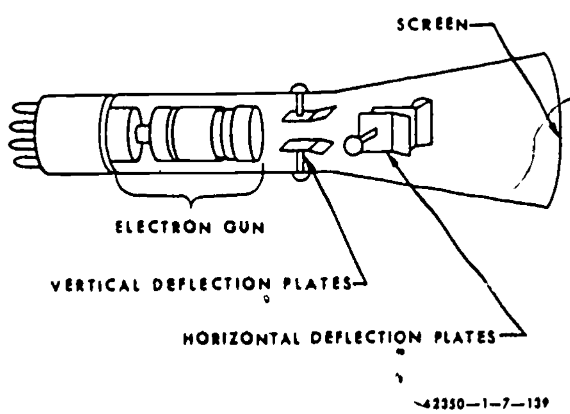


Figure 133. Cross section of cathode-ray tube.

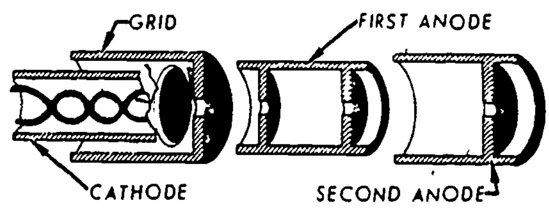


Figure 134. Parts of an electron gun.

20-59. At the left-hand end of the tube, you will notice the electron gun is an assembly consisting of the cathode, filament, grid, first anode, and second anode. Directly to the right of the electron gun are two pairs of deflection plates. One pair—the vertical deflection plates—is mounted in a horizontal plane, and the second pair is mounted in a vertical plane and provides horizontal deflection of the electron beam.

20-60. *The electron gun.* The five parts of this gun act together to shoot a stream of electrons against the fluorescent screen of the cathode-ray tube (CRT). The gunlike action of shooting a stream of electrons gives this unit its name. Figure 134 shows the arrangement (in cross section) of the parts of an electron gun.

a. Filament and cathode. The filament and the cathode form a single unit. In the figure, the cathode appears as a small metal container; one end is open to permit the entry of the filament. The other end of the cathode is shaped like a cup; it is filled with barium oxide or thorium oxide. Use of these compounds increases the number of electrons that will be given off by the heated cathode. The filament is prevented from touching the sides of the cathode by a plasterlike insulating material. When the cathode is heated by the filament, electrons are boiled out of the barium oxide or thorium oxide to form a cloud or space charge around the cathode.

b. Grid. The grid resembles a tin can that has been slipped over the end of the cathode. A hole in one end of the grid provides a passageway through which the electrons move toward the first anode. This element regulates the number of electrons that strike the fluorescent screen. The regulation results from making the grid negative with respect to the cathode. A very negative grid will permit some electrons to pass through the grid opening. This means that by varying the amount of negative potential on the grid, the intensity or brilliance of the image on the fluorescent screen can be controlled.

c. First and second anodes. The first anode is

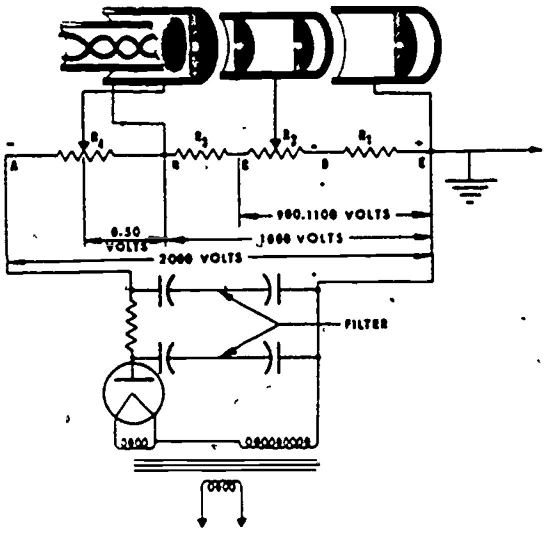


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Figure 135. Electron gun potentials.

a small can that has a hole punched in the center of each end. The second anode is a larger can having one end cut away and a hole punched in the center of its opposite end. Both anodes focus the electrons into a sharp, fast-moving stream. When the electrons leave the cathode, they are slow moving and their direction is not defined. The two anodes work as a unit to *focus* this cloud of sluggish electrons into a sharp, fast-moving beam. They do this in much the same way that a lens focuses the beam of a flashlight.

20-61. *Electron gun potentials.* Except for the second anode, whose potential is ground or zero, all of the elements of the electron gun are at negative potentials.

20-62. Figure 135 shows resistors R_1, R_2, R_3, and R_4 forming a bleeder for a high-voltage power supply. Note that the positive end of the bleeder is grounded. This brings up the subject of relative potentials and what must be done to all the other potentials along the bleeder when the positive terminal of a bleeder is grounded.

20-63. Reading from right to left in figure 135, the highest negative potential is at point A. Reading from left to right the highest positive potential is at point E. Therefore, E is a higher positive point than D; D is a higher positive point than C; C is higher than B; and B is higher than A. You should recall from the previous discussion of vacuum tubes that electrons always move toward the highest positive potentials. These charges are given off by the cathode which is connected to point B. Because the first anode is connected to a point of higher positive potential, electrons will move from the cathode toward that particular anode.

20-64. The second anode is connected to a point (E) which has a higher positive potential than the first. The difference in potential between the two anodes is from the first toward the second anode. Electrons arriving at the first anode from the cathode are caught in this electrostatic field and whipped forward through the openings in the anodes at an ever-increasing rate. By the time the electrons reach the opening in the second anode, they are traveling fast enough to be thrown the length of the tube, where they strike against the fluorescent screen.

20-65. The greater the difference in potential between the anodes, the stronger the electrostatic field. The stronger the field, the faster the movement of the electrons toward the fluorescent screen. You can increase the strength of the electrostatic field by moving the focus control (R_2) toward point C. This not only makes the first anode more negative, it also, in effect, makes the second anode more positive. Increasing the difference in potential between the anodes squeezes the electrons into a narrower and sharper beam.

20-66. If the focus control (R_2) is moved toward point D, the difference in potential between the anodes is reduced. This reduces the strength of the electrostatic field, and the beam striking the fluorescent screen becomes thick and fuzzy.

20-67. *Operation of the grid.* Look at figure 135 again. Note that the grid is connected to a point that is more negative than the cathode. Electrons leaving the cathode must pass this negative grid before they can get to the first anode. If the grid is slightly negative, only a few electrons will be repelled toward the cathode; most of them will get through. If the grid is made progressively more negative by moving the intensity control (R_4) toward point A, fewer and fewer electrons will be able to get through the grid opening. Finally, when the grid reaches its maximum negative value, none of the electrons will be able to get through.

20-68. Making the grid more negative reduces the intensity of the image on the flourescent screen. You can make the grid so negative that no image will be visible. Normally, you make the grid potential barely negative enough to hold back part of the electron stream. If you want to brighten the spot, reduce the negative potential by turning up the intensity control. Never make the spot any brighter than is necessary; doing so can damage the screen.

20-69. *The deflecting plates.* To produce the movement of the electron beam over the entire

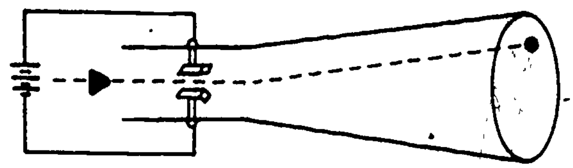

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Figure 136. Vertical deflection of the electron beam.

screen surface, two pairs of deflection plates are used. Referring to figure 133, note that the plates are located to the right of the second anode in such a position that the electron beam passes through the square opening formed by the four plates.

20-70. The plates are named in accordance with the direction in which they cause the beam to move. That is, the horizontal deflection plates move the beam across the screen in a horizontal direction, and the vertical deflection plates move the spot up or down in a vertical direction.

20-71. So that voltages can be applied directly to the deflection plates, connections or binding posts on the outer side (or the back) of the scope are in direct contact with the deflection plates. The connections on the back are usually moved from their normal position before they are used. For the vertical deflection plates, the ground connection is attached to the bottom vertical plate and the other connection is attached to the top deflection plate. If a DC voltage is impressed across these connections with the negative side to ground, the bottom vertical deflection plate will be negative and the top plate positive.

20-72. Since the top plate is positive, it will attract the electron stream. On the other hand, the bottom plate, which is negative, will repel the electron stream. This condition causes the beam to be bent upward as it passes between the plates so that it produces a dot on the screen at some point above its center. This is illustrated in figure 136. If the applied voltage is reversed, the beam is bent downward so that the dot appears below the center of the screen. So, you see that one function of the oscilloscope is to determine the polarity of an unknown voltage.

20-73. You have just learned the effect of polarity on the position of the dot. But how does a variation in the amount of potential difference between the plates affect the position of the dot? With twice as much voltage applied to the vertical deflection plates as was used before, you will find that the dot moves twice as far from its center position. If the voltage is increased, the dot will move farther from the center of the screen. If the voltage is decreased to one-half its original value, the dot will be only one-half as far from the center of the screen as it was originally. This shows that the distance of the dot from the center is a direct indication of the amount of voltage that is connected across the plates. These experiments show that the oscilloscope can be used as a voltmeter. The characteristic that makes it a good DC voltmeter is its very high input resistance.

20-74. The horizontal deflection plates can also be used to influence the electron beam; their effect being similar to that of the vertical deflection plates. If a voltage is applied to the horizontal deflection plates as shown in figure 137, the nearest plate (in the figure) will be negative and the other one will be positive. As the electrons speed between the plates, the nearest plate repels the electron stream and the other plate attracts it. As a result, the electron beam is bent away from the center and the dot moves to a point that is to be right of center (looking at the end of the CRT). A reversal of voltage causes the dot to appear at a point to the left of center. An increase of voltage will move the dot farther from the center, whereas a decrease of voltage will bring the dot closer to the center of the screen. Although the horizontal deflection plates can also be used to measure voltage, they are generally used for another purpose.

20-75. The deflection produced when an AC voltage is applied to the vertical deflection plates

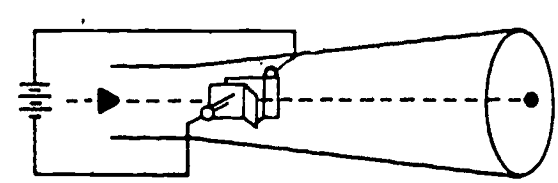

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Figure 137. Horizontal deflection of the electron beam.

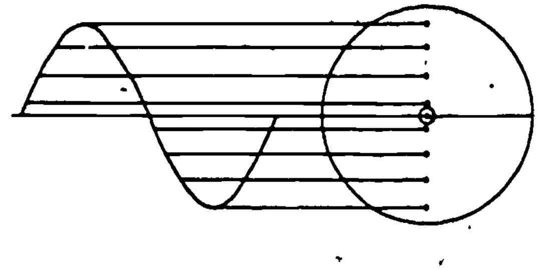

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Figure 138. One cycle per second applied to the vertical deflection plates.

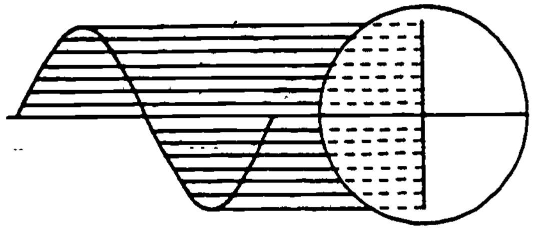

Figure 139. Line image on the scope.

occurs in exactly the same manner as that which results when a DC voltage is applied. Actually, the displacement of the beam from its normal center position is a function of the field strength existing between the two deflection plates. As the previous examples have shown, the displacement of the spot from its normal center position is a measure of the voltage difference existing between the two plates. An AC peak voltage of 10 volts will alternately displace the spot or deflect the beam the same distance on either side of the center position. A DC voltage of 10 volts applied first to one and then to the other of the two plates will give the same results.

20-76. For a very low frequency, the dot can be seen to move up and down from one extreme to the other. At 60 cycles per second, the image on the screen will appear as a straight line, since the dot travels so rapidly that its motion from point to point along the line cannot be seen. Suppose, for a moment, that a frequency of 1 cycle per second is applied to the vertical deflection plates, as shown at the left of figure 138. Since only the force is acting on the electron beam, the field set up by the applied deflecting voltage is determined by the instantaneous amplitude of this voltage. The normal position of the spot is indicated in the figure by the dot within the circle in the center of the screen. The applied voltage starts at zero and increases in one direction until maximum value is reached. If the polarity of this alternation is such that it makes the top vertical deflection plate positive with respect to the bottom vertical deflection plate, the beam and spot will move upward. As the voltage increases, the spot will move through the various positions shown in figure 138 until it reaches a maximum position at the moment the peak of the alternation is reached. Then the downward half of this alternation begins and the spot moves toward its initial starting position. This point is reached when the first alternation is completed, and the AC voltage is again zero.

20-77. The alternation now starts in the opposite direction, and the bottom vertical deflection plate is positive with respect to the top vertical deflection plate. The resulting beam is deflected downward, and the spot moves in that direction. As the amplitude of this downward alternation increases, the spot moves farther and farther away (down) from its normal center position until it reaches its farthest point at the time the peak amplitude is reached. Then as the voltage starts to decrease (the last quarter-cycle of the sine wave), the spot moves upward toward its initial starting point, finally reaching the middle of the screen when the AC voltage is again at zero. Figure 138 shows the position of the dot at various points along the sine wave of voltage as it is applied to the vertical deflection plates.

20-78. In actual practice, the frequency of the voltage applied to the plates is such that it is impossible to see the spot moving from point to point. Instead, the recurrent action of the AC voltage causes the spot to trace and retrace its path at such a speed that, because of the persistency of vision and the persistency of the screen, a solid line pattern is seen. The scope reads peak-to-peak voltages. It can be used as an AC voltmeter because it has a high input impedance and because the beam of electrons can move up and down as rapidly as the highest frequency of AC changes. Figure 139 shows the solid-line pattern that is visible when the frequency is too high for the movement of the dot to be observed.

20-79. What has just been explained about the vertical deflection plates is also true of the horizontal deflection plates. If an AC voltage is applied to the horizontal deflection plates without any vertical deflection, a horizontal line will be visible. When only the sweep voltage is applied, you can observe a horizontal line (time-base line) whose length depends on the position of the horizontal gain control.

20-80. *The time base.* By now you are aware that the scope can be used as a voltmeter. You

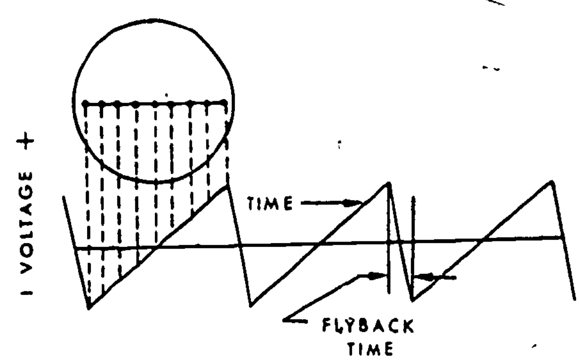

Figure 140. The sweep voltage.

also know that the primary function of the CRT used in the oscilloscope is to observe changing voltage. But what happens to a voltage with respect to time from one moment to the next is also important.

20-81. The normal representation of a changing voltage with respect to time appears as a graph. The horizontal line of the graph represents time, and the vertical line represents the magnitude of the voltage. Rather than draw individual graphs of voltage on paper, it was determined that the scope could be used to make the graph if there were some means of moving the dot from one side of the scope to the other at a constant rate. That means became a reality in a device called a time-base generator. This device causes the dot to start at the left side of the screen and move to the right side at a constant rate. In this way the dot moves a certain distance farther to the right during each succeeding unit of time. Another name for the time-base generator is the sweep generator. It is given this name because of the action of the dot on the screen. After the dot moves across the screen, it returns to the starting point, and the operation starts all over again. This movement of the dot is similar to the motion of a broom in sweeping; hence, the dot "sweeps" across the screen.

20-82. When the sweep generator moves the dot across the screen, it is actually applying a varying voltage to the horizontal deflection plates. When the dot is on the left side of the screen, the electron beam has been deflected to the left. At that moment, the left horizontal deflection plate is positive with respect to the right one, and the right one is negative with respect to the left one. As the spot moves toward the center of the screen (horizontally), the voltage difference between the plates decreases until both are at the same potential. The dot is then at the center of the screen. The dot continues to move toward the right at a constant rate because the voltage on the deflection plates reverses, and the plate on the right becomes more and more positive, while that on the left becomes more and more negative.

20-83. Figure 140 is a graph representing the relationship between sweep voltage and time. This illustration shows a scope "picture" when voltage is applied to the right deflection plate. When the right plate is negative with respect to the left, the voltage appears below the zero axis on the graph. When the right deflection plate is positive with respect to the left plate, the voltage is shown above the zero axis. The position of the spot at several instances during the time the *sweep voltage* is being applied is shown in the complete figure. The dashed lines connect each dot with the voltage that caused the dot to appear in that position.

20-84. Since the dot is repeatedly swept across the screen, the graph of this sweep voltage is continuous. To start over again the dot has to return to the left side of the screen. The time required to make this return trip is called the flyback time and is very small compared to the time that the dot is being swept. Flyback time is shown as a near vertical line on the graph, while the sweep voltage closely resembles the outline of sawteeth. For this reason, the *sweep voltage* is often referred to as a *sawtooth voltage*.

20-85. A switch on the scope permits the horizontal deflection plates to be connected to the external binding posts or to the connections of the sweep generator. This switch is a part of all oscilloscopes. On some scopes, switching is done by turning the frequency range selector. On others, it is either a part of the timing sync control or a part of the horizontal amplifier control.

20-86. The varying voltages which are to be observed on the oscilloscope make their changes in very small increments of time. To make these changes visible, it is necessary to move the dot across the screen at a very fast rate. This will give the effect of a constant pattern. The greater the speed with which the dot is moved across the screen, the more times per second it can be swept across. The number of times the dot is swept across the screen each second is known as the *sweep frequency*, and the length of time it takes for the dot to trace the line is the *sweep time*. The latter is usually measured in terms of microseconds (millionths of a second). This concludes the discussion of the principles of operation of the cathode-ray tube as used in an oscilloscope.

20-87. **Electron Tube Identification.** There are two ways of identifying electron tubes. The first is by designation, where the numbers and letters serve as a code. The second is by consulting the tube manuals that are prepared by various tube manufacturers. There are four parts of the coded designation and each represents the following:

(1) Number—filament or heater voltage.
(2) Letter—type of function of the tube.
(3) Number—useful elements.
(4) Letter—size or construction.

Let's take a 5Y3G to illustrate.

(1) Filament or heater voltage—5 (5 volts).
(2) Tube function—Y (rectifier; letters "U" to "Z" also denote rectifiers).

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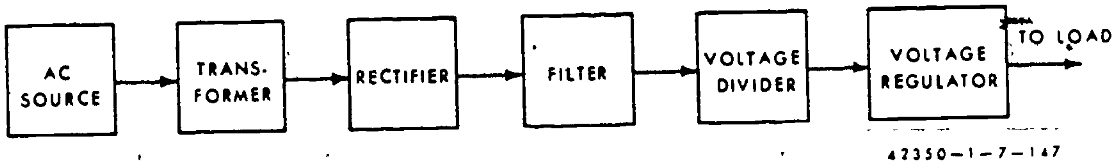

Figure 141. Power supply block diagram.

(3) Useful elements—3 (duodiode).
(4) Construction—G (glass envelope).

Thus, a 5Y3G is a glass-inclosed duodiode rectifier that requires 5 volts filament voltage. Now, see what you can do with type 50L6GT (L represents beam power amplifier) before proceeding further. If you figure "beam power amplifier with six useful elements that operates on 50 volts and is housed in some sort of glass container," you are correct. This particular tube uses heater voltage, and the heater and cathode are separate elements. GT is the code for a certain glass envelope that is somewhat smaller than the conventional size.

20-88. Since thousands of different types of tubes are manufactured, there are numerous exceptions to the system. The situation is even more confused with transmitting tubes because the manufacturer of these tubes has his own method of assigning numbers and letters. However, when possible, a faulty tube should be replaced with one made by the same manufacturer.

20-89. Since there is a lack of standardization and since a simple designation does not disclose the many operating characteristics of the various tubes, personnel often have to refer to a tube manual to obtain specific information.

20-90. Many of the electronic control systems and components you will work on require a special type of power for operation. This power is provided by built in or separate power supplies. In the following section we will discuss power supplies and their operation.

21. Electronic Power Supplies

21-1. Electronic power supplies have a wide variety of applications throughout the Air Force. For example, many electrical shops have electrical testers, such as the T-35 or T-170, that contain power supplies. The oscilloscope (discussed elsewhere in this volume) has a power supply that is an integral part of the set. Since you are required to repair electrical shop test equipment, it is necessary that you have a working knowledge of power supplies.

21-2. Vacuum tubes require various values of voltage for their different elements, such as filament, screen grid, and plate. Except for the filaments, which can be heated with AC or DC, the vacuum tube elements require DC voltages. A typical power supply for an electronic device is shown in the block diagram, figure 141.

21-3. The AC source can be any source of alternating current. You know that 115-volt, 60-Hz AC is typical of that encountered commercially. In aircraft application, 400 Hz power sources are most common.

21-4. The six elements of the power supply shown in figure 141 are not all present in every application. However, the AC source of power

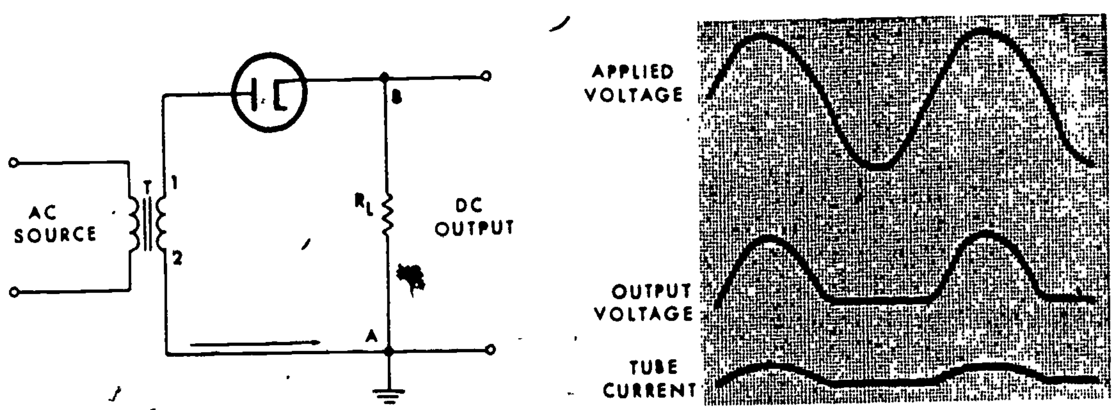

Figure 142. Half-wave rectifier.

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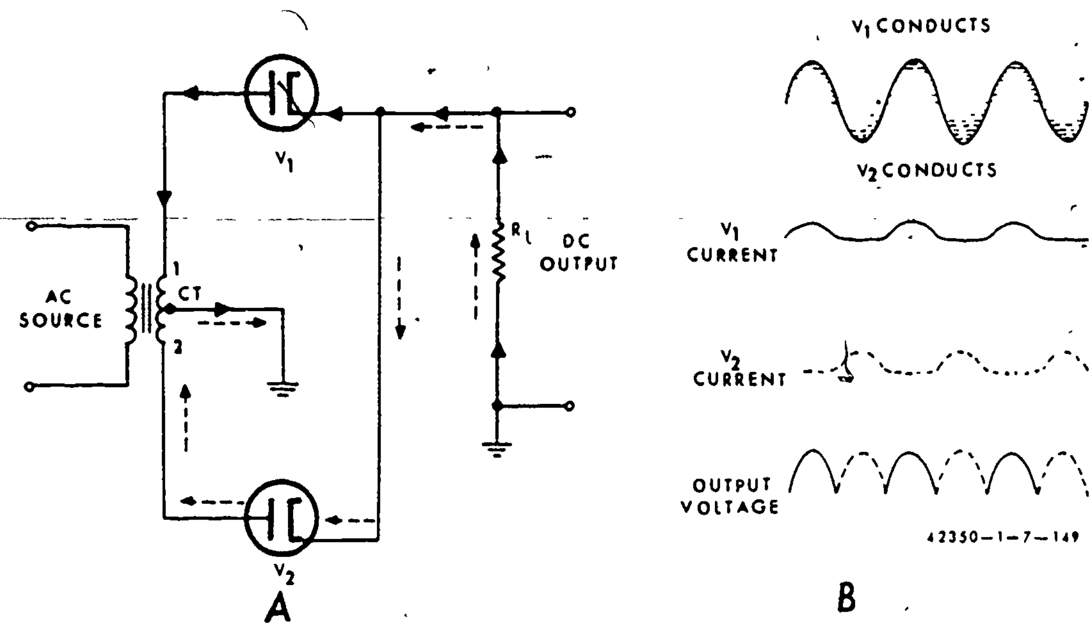

Figure 143. Full-wave rectifier.

and the rectifiers are essential and could provide the necessary power. The other elements contribute to the ability of the power supply to provide a wider range of output voltages that are smoother and more dependable.

21-5. **Rectifier Circuits.** Earlier in this chapter, you learned that a diode vacuum tube acts as a rectifier. There are various types of circuits that are used for rectification—among these are half-wave rectifiers, full-wave rectifiers, bridge rectifiers, and polyphase rectifiers.

21-6. *Half-wave rectifiers.* The half-wave rectifier shown in figure 142 is a circuit that uses a single diode to rectify an alternating current. T is the power transformer whose primary is connected to an AC source. The rectified current flows through the load resistor. The transformer secondary applies an AC voltage between the plate and cathode of the diode. However, current flows only during that half-cycle when the plate is positive with respect to the cathode. Current flows in only one direction, as indicated by the arrows. However, the current is a pulsating type, as shown by the waveshape. The frequency of the pulses is called ripple frequency. For each type of AC input there is one pulse or one ripple. Therefore, in this type of rectification, the ripple frequency is equal to the AC input frequency.

21-7. The current flows through R_L and causes a voltage drop to exist across it. Since the current flows from point A to point B in R_L, point A is negative with respect to point B. Because the current through R_L is pulsating, the voltage developed across it is also pulsating. From the wave shapes of the output voltage and current, you can see why this type of rectifier is called a half-wave rectifier.

21-8. If the tube is reversed so that the plate is connected to point B and the cathode to point 1 of the transformer secondary, current flows through R_L in the opposite direction (from B to A). Since A is at ground potential, the output voltage across R_L is negative in this case.

21-9. The output voltage of a half-wave rectifier drops to a low value if a load requiring much current is connected to the output terminals. Half-wave rectifiers are therefore used where current drain is low and high voltages are required. The high-voltage power supply circuit for an oscilloscope is usually a half-wave rectifier.

21-10. *Full-wave rectifiers.* The half-wave rectifier finds many applications but it has several disadvantages. Some of these disadvantages are overcome by the use of a full-wave rectifier. A full-wave rectifier uses both halves of the AC cycle in its rectification process. A typical full-wave rectifier is shown in figure 143,A. If you compare this circuit with that of a half-wave rectifier, you will note the following two differences: (1) The full-wave rectifier employs two diodes, and (2) the high-voltage transformer secondary of the full-wave rectifier is center-tapped (CT).

21-11. Note that the center tap is returned to ground and then through R_L to the cathodes of V_1 and V_2. Point 1 of the high-voltage winding is connected to the plate of V_1 and point 2 is connected to the plate of V_2. Thus, the AC

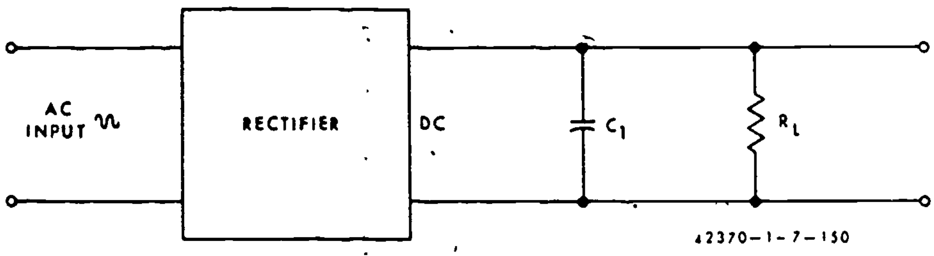

Figure 144. Rectifier with capacitor-filtered output.

voltage developed from 1 to CT is applied across V_1 and the voltage from 2 to CT is applied across V_2.

21-12. The two diodes conduct alternately because, at any given instant, one plate is positive and the other negative; a half-cycle, later the polarity of the voltages, is reversed. The direction and path of current through V_1 is shown by the solid arrows and through V_2 by the dotted arrows. Both currents flow through the load resistor in the same direction. The output and input voltage wave shapes are shown in figure 143,B. Note that the frequency of the pulses is twice the frequency of the AC source. If 60-Hz AC is rectified by a full-wave rectifier, the ripple frequency is 120 Hz.

21-13. In most applications, the two diodes are included in one envelope. When V_1 is conducting, its plate is positive. The cathode of V_2 is at the same potential; however, its plate is negative at the same instant. Each tube must, therefore, be capable of withstanding twice the peak voltage applied to the tube in the reverse direction. This is known as the inverse peak voltage and must be taken into consideration in the design of a full-wave rectifier.

21-14. In full-wave rectifiers, where half of the high-voltage secondary is connected across each diode, the DC output voltage is proportional to half of the secondary's AC voltage. On the other hand, in half-wave rectifiers, the entire voltage of the high-voltage secondary is applied across the diode. The high-voltage secondary winding of a full-wave rectifier must, therefore, provide approximately twice the AC voltage to give the same DC output. A major disadvantage of full-wave rectifiers is that transformers of higher voltage output are necessary. At higher values of voltage, a difficult problem is created because of the excessive amount of insulation required. As a result, where thousands of volts are supplied, half-wave rectifiers are usually used. However, full-wave rectifiers are used in power supplies which require a high-current drain at a lower voltage.

21-15. **Filters.** You have seen that the rectifier changes AC voltage to DC voltage. However, the DC voltage output of the rectifier is a pulsating DC voltage; that is, it has pulses or ripples. These ripples may be considered to be an AC voltage superimposed on a DC voltage. If the output from a rectifier is to be used to provide voltages for certain vacuum tube circuits, the ripple must be removed or reduced, otherwise distortion may occur. The filter of a power supply is the device that removes or reduces the magnitude of the AC component (ripple) of a rectifier so that only the DC component is effective.

21-16. *Individual reactances as filters.* A reactance that opposes a change in voltage (or current) by storing energy and then releasing this energy back to the circuit may be used as a filter.

21-17. You have seen that a capacitance opposes a voltage change across its terminal by storing energy in its electrostatic field. Whenever the voltage tends to rise, the capacitor converts this voltage change to stored energy. When the voltage tends to fall, the capacitor converts this stored energy back to voltage. The use of

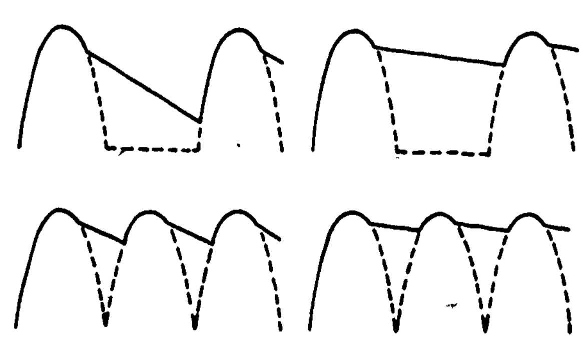

Figure 145. Capacitor-filtered output wave shaper.

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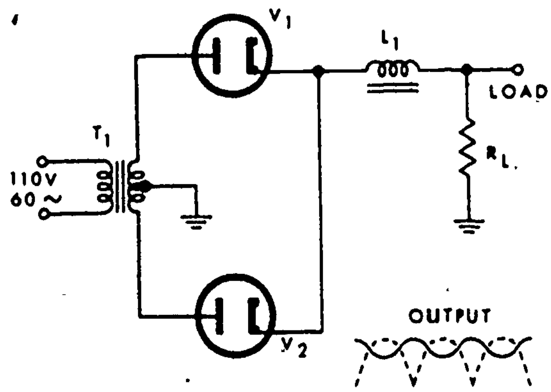

Figure 146. Rectifier with inductor-filtered output.

a capacitor for filtering the output of a rectifier may be seen in figure 144. The rectifier is shown as a block in the illustration, and the capacitor C_1 is connected in parallel with the load R_L.

21-18. The capacitor C_1 is chosen to offer very low impedance to the AC ripple frequency and very high impedance to the DC component. The ripple voltage is, therefore, bypassed to ground through the low-impedance path, while the DC voltage is applied unchanged to the load. The effect of the capacitor on the output of the rectifier may be seen in the wave shapes shown in figure 145. Dotted lines show the rectifier output; solid lines show the effect of the capacitor. Half-wave and full-wave rectifier outputs are shown. The capacitor C_1 charges when the rectifier voltage output tends to increase and discharges when the voltage output tends to decrease. In this manner, the voltage across the load R_L is kept fairly constant.

21-19. An inductance may be used as a filter, because it opposes a change in current through it by storing energy in its electromagnetic field whenever current tends to increase. When the current through the inductor tends to decrease, the inductor supplies the energy to maintain the flow of current. The use of an inductor for filtering the output of a rectifier is shown in figure 146. Note that the inductor L_1 is in series with the R_L load.

21-20. The inductance L_1 is chosen to offer high impedance to the AC ripple voltage and low impedance to the DC component. Therefore, for the AC ripple, a very large voltage drop occurs across the inductor and a very small voltage drop occurs across the load R_L. For the DC component, however, a very small voltage drop occurs across the inductor and a very large voltage drop occurs across the load. You can see the effect of an inductor on the output of a full-wave rectifier in the output wave shape. Note how the ripple has been attenuated in the output voltage.

21-21. *LC filters.* Capacitors and inductors are combined in various ways to provide more satisfactory filtering than can be obtained with a single capacitor or inductor. Several combinations are shown schematically in figure 147. Note that the L, or inverted L type, and the T type filter sections resemble schematically the corresponding letters of the alphabet. The pi type filter section resembles the Greek letter pi (π) schematically.

21-22. The filter sections shown in figure 147 are similar in that the inductances are in series and the capacitances are in parallel with the load. The inductances must, therefore, offer a very high impedance and the capacitors a very

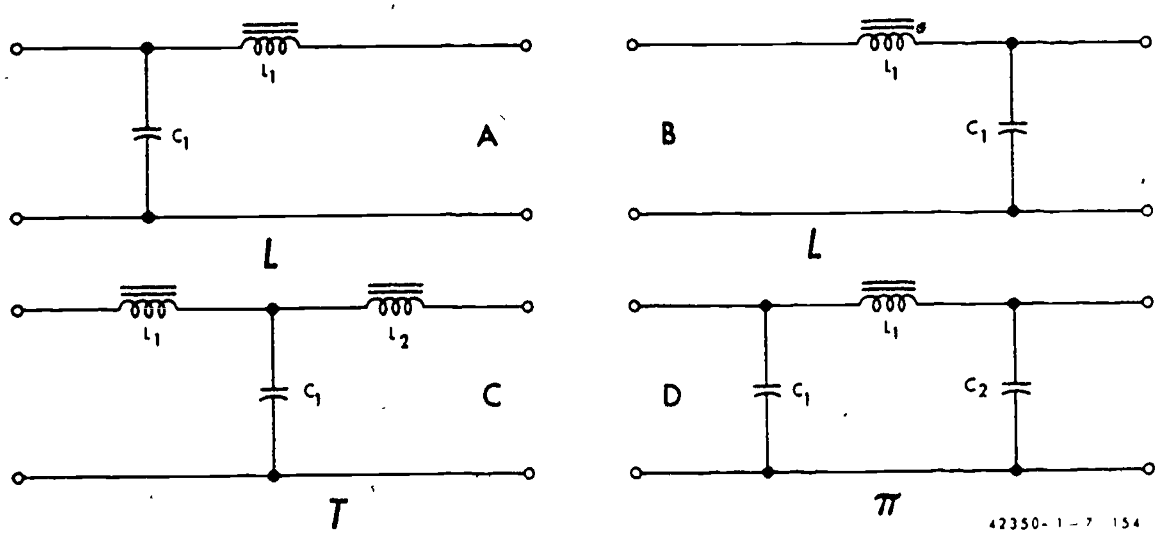

Figure 147. Types of LC filters.

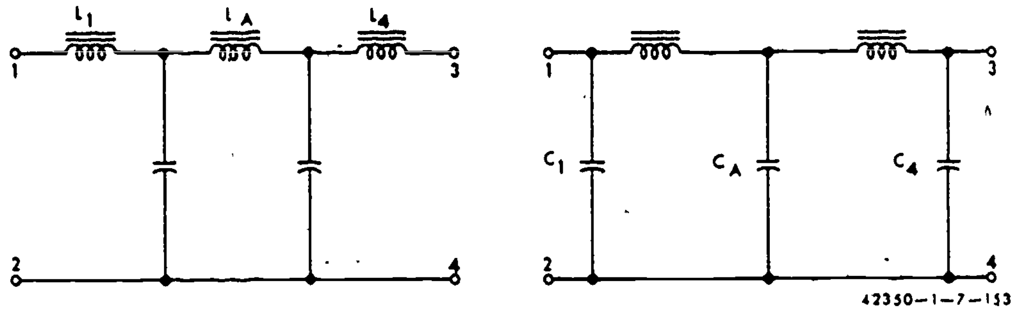

Figure 148. Two-section filters.

low impedance to the ripple frequency. Since the ripple frequency is comparatively low, the inductances are iron-core coils having large values of inductance (several henrys). Because they offer such high impedance to the ripple frequency, these coils are called chokes. The capacitors must also be large (several microfarads) to offer very little opposition to the ripple frequency. Because the voltage across the capacitor is DC, electrolytic capacitors are frequently used as filter capacitors. Be sure you observe the correct polarity in connecting electrolytic capacitors.

21-23. More than one section of a given type of filter may be combined to improve the filtering action. An illustration of two-section filters is shown in figure 148.

21-24. LC filters are also classified according to the position of the capacitor and inductor. A capacitor-input filter is one in which the capacitor is connected directly across the output terminals of the rectifier. Filter sections A and D in figure 147 are examples of the capacitor-input filters. A choke-input filter is one in which a choke precedes the filter capacitor. Filter sections B and C in figure 147 are examples of choke-input filters.

21-25. The most common type of filter used with half-wave rectifiers is the *capacitor input, pi type* filter shown in figure 149. When the electrons flow in the path shown by the solid arrows, the capacitors are charged as shown. If R_L is not connected and the capacitors are assumed to have no leakage, the output voltage is equal to the peak value of the AC voltage applied from the secondary of the transformer. If R_L is connected, the capacitors discharge through it, as shown by the dotted arrows. The extent to which the capacitors discharge depends upon the value of the load. The voltage falls rapidly as the current drain increases.

21-26. The resistor R shown as part of the filter is called a bleeder resistor. It is used to discharge the capacitors when the equipment is turned off. The resistor should be large; it should not draw more than 10 percent of the rated current. The output voltage of a rectifier with a capacitance-input filter is approximately peak value if the current drain is low, but the load must be extremely light. Because the output voltage depends on the value of the load, a capacitance-input filter has poor voltage regulation. If a full-wave rectifier is used with a capacitance-input filter, there is a slight improvement in the filtering action. However, the voltage regulation is still poor.

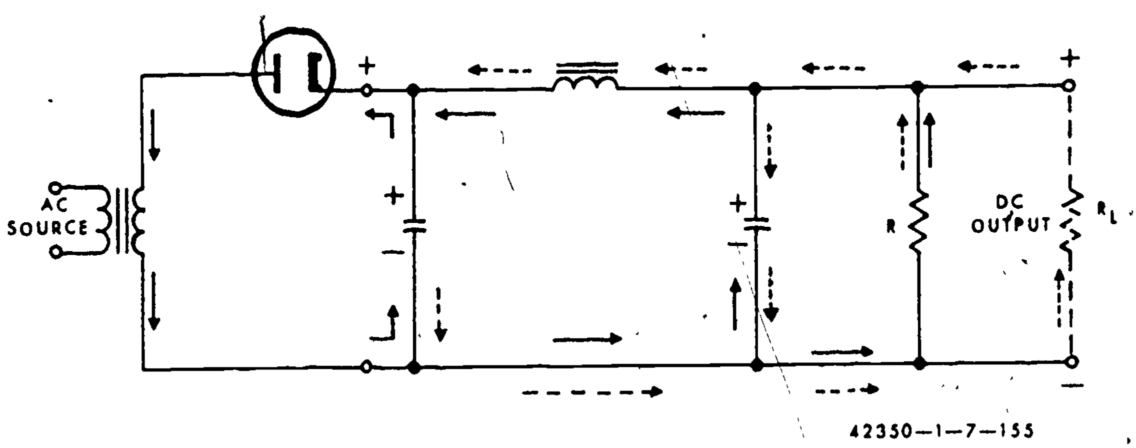

Figure 149. Half-wave rectifier with capacitor-input pi type filter.

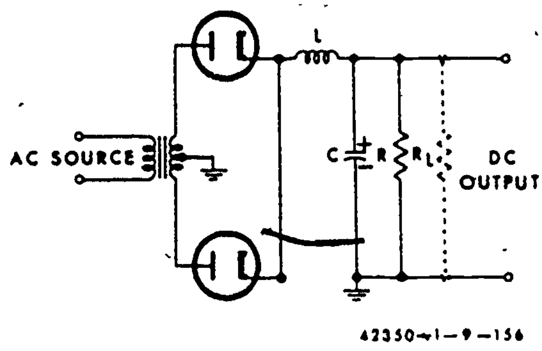

Figure 150. Full-wave rectifier with choke-input filter.

21-27. *Choke-input filters* provide better voltage regulation than capacitance-input filters. As a result, choke-input filters are used to a great extent in power supplies for transmitters and other electronic circuits that require considerable power. However, the choke-input filter requires full-wave rectification and gives less DC output voltage for a given AC input.

21-28. A full-wave rectifier with a choke-input filter is shown in figure 150. The pulsating current from the full-wave rectifier flows through the choke and the load. The choke opposes the changes in current and reduces the magnitude of the ripple. The capacitor filters the AC component further. When a small amount of current is drawn, the voltage drops rapidly and then remains fairly constant over a wide range of load. This type of filter gives good current regulation under changing load conditions or heavy drain.

21-29. *RC filters*. In many applications, a resistor is used to replace the coil in a filter to save expense. A disadvantage of this type of filter is that the resistor offers the same impedance to the DC voltage as to the AC component. In addition, current flow through the resistor causes power to be dissipated in the form of heat.

21-30. From our discussion up to this point, you have seen that filters are an important part of an electronic power supply. Now let us take a look at a low-voltage power supply and see just how the output voltage is affected by the filter.

21-31. **Power Supply Systems.** A wide variety of power supply systems is used in electronic units, depending on the application of the unit. There are low-voltage systems, medium-voltage systems, high-voltage systems, and in some cases, combination type systems. We will limit our discussion to a low-voltage system.

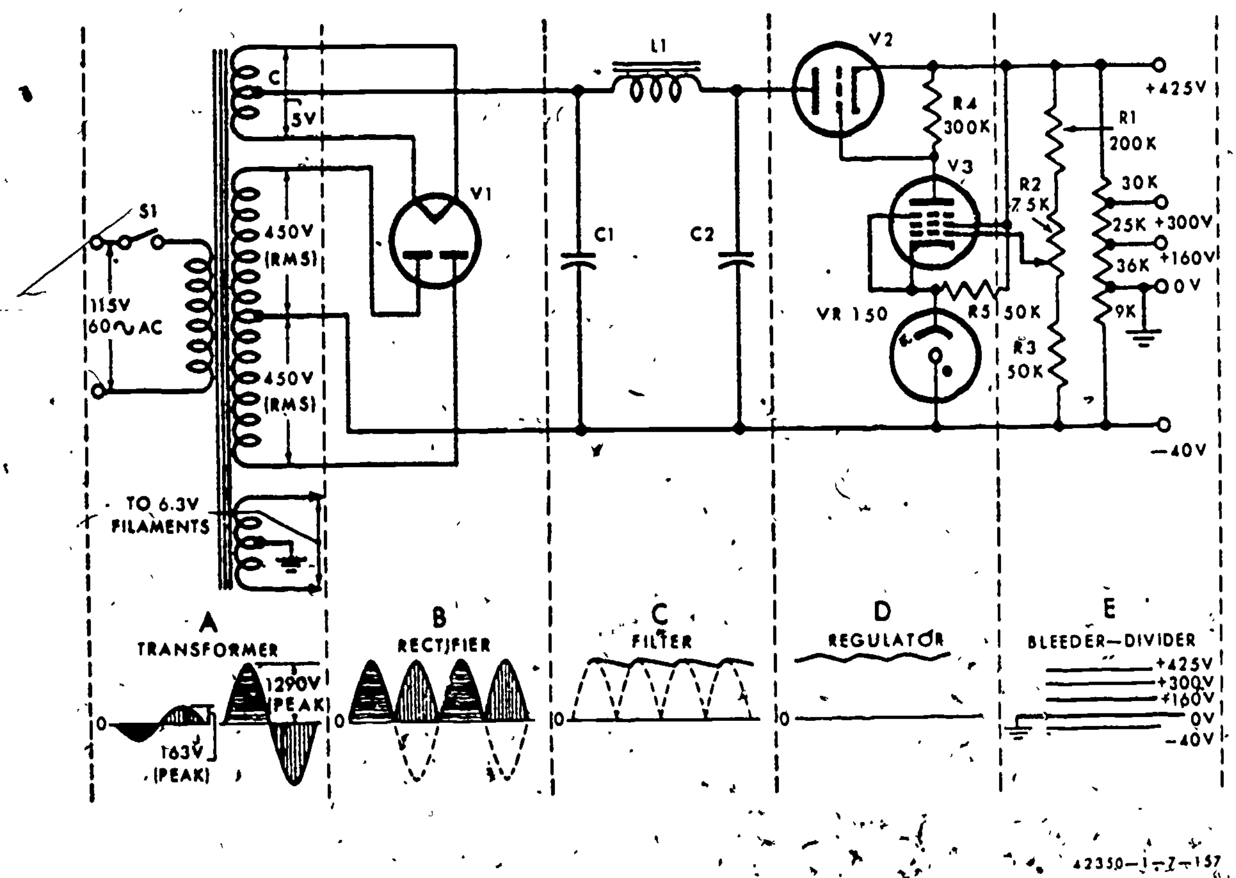

Figure 151. Low-voltage power supply.

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21-32. A complete power supply system to supply low voltages is shown in figure 151. This circuit shows a full-wave rectifier, filter section, voltage-regulator circuit, and voltage-divider network all combined in a single power supply unit. This circuit arrangement is typical, and if additional filtering is required, chokes or capacitors can be added after capacitor C_2. The function of the power supply is summarized here in terms of the complete unit.

21-33. Referring to figure 151, you see that the input voltage to the power transformer primary is 115-volt, 60-Hz AC, which is a standard value of power-line voltage. The transformer has three secondary windings, two being low-voltage windings and the third a high-voltage winding. (The term "high voltage" is used here to make a distinction between the filament voltage and the voltage applied to the plates of the rectifier tube.) In one of the low-voltage windings, the voltage is stepped down to a value of 6.3 volts and provides the power for the filaments of all 6.3-volt tubes in the power supply and its associated equipment. The other low-voltage winding provides a stepped-down voltage of 5 volts for operation of the filament of rectifier tube V_1. In the high-voltage winding, the voltage is stepped up from the input value of 115 volts (rms) to a total secondary value of 1290 volts peak or approximately 900 volts rms. This value represents a step-up of almost eight times. Waveforms showing the voltage on the primary of the transformer and the stepped-up voltage of the high-voltage secondary winding are shown in item A.

21-34. The high-voltage secondary of the power transformer is tapped in the center to provide the common B-minus return lead for the power supply. This tap is placed at the electrical center of the winding so that equal voltages are applied to the plates of rectifier tube V_1. From each end of the secondary winding to the center tap, approximately 450 volts (rms) is available, and this voltage is applied to the plates of the rectifier tube.

21-35. The rectified voltage appears at the center tap of the 5-volt filament transformer in item C. This winding is center tapped so that the plate current for the two sections of the full-wave rectifier will divide equally in each filament lead. The rectified pulses then will be equal in amplitude as shown in the waveform in item B. The operation is as follows: When switch S1 is closed, the 115-volt, 60-Hz AC line voltage is applied to the primary of the power transformer. This voltage is indicated by the smaller waveform in item A. The larger waveform in A represents the stepped-up voltage across the full high-voltage secondary winding, which is 1290 volts (peak).

21-36. The two plates of the rectifier tube V_1 conduct alternately as each plate is made positive by the alternating voltage on the transformer secondary. Pulses of current flow from the filament to each plate as each plate goes positive. Since each plate is in operation for only half of an input cycle, the current through the rectifier tube always flows in the same direction as the action swings from one plate to the other. The current in the filament line, therefore, shows a continous pulsating current flow in this one direction. The waveform representing this action is shown in item B. (In practice, this waveform appears only when there is no filter connected to the rectifier tube output. When the filter is used, as shown in the diagram, the actual waveform is similar to that shown in item C.)

21-37. The rectified current pulsations are filtered and smoothed by the action of C_1, L_1, and C_2, which are connected in a simple π-filter arrangement. The charge and discharge of the filter capacitors smooth the gaps between the rectified current pulses. The current flowing through the choke builds up a varying magnetic field, and this field tends to retard the flow of current as it increases and to maintain the current flow when it collapses. The effect of this is to produce a more constant flow of current through the circuit. The waveform at the filter output in item C is represented by the heavy line superimposed upon the peaks of the dotted current pulses. The capacitor input filter of the circuit allows a higher voltage output with a lower load current than that of a choke-input filter. However, a choke-input filter would provide a more constant value of output voltage with less ripple under changing load conditions.

21-38. The voltage regulator circuit provides a constant value of output voltage despite variations in the input voltage or changes in load conditions. The pass tube V_2 is in series with the output circuit. Resistor R_4, tube V_3, and glow tube VR-150 are connected in series across the output. The VR tube holds the cathode of V_3 at a constant potential with respect to ground. The setting of potentiometer R_2 determines the bias on the control grid of V_3. The current passing through resistor R_4 establishes the bias voltage which determines the interval resistance of V_2. These conditions are set to provide the rated current across the voltage divider. When the load draws a larger-than-rated current, the terminal voltage of the power supply tends to decrease. This places a more negative bias on the grid of V_3 and less current flows through V_3. The reduced current through R_4 provides a less negative

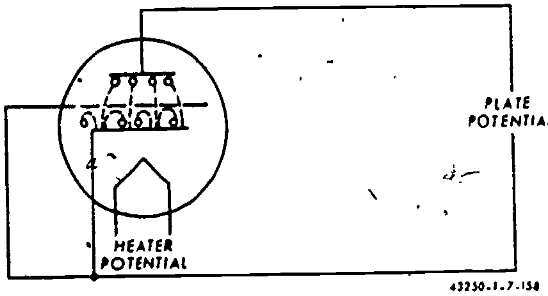

Figure 152. Triode with grid connected directly to cathode.

bias on the grid of V_2 and decreases the internal resistance of this tube. Consequently, the voltage drop across the tube becomes less and the output voltage increases. In a well-designed circuit, the reduced voltage drop across tube V_2 is just sufficient to compensate for the reduced output voltage, and the voltage across the output terminals of the power supply is restored automatically to the rated value. When the terminal voltage increases, a similar action occurs in the opposite direction, and the output voltage remains constant. The output voltage appearing across R_4, V_3, and the VR tube is a fairly constant DC voltage, shown in item D.

21-39. The bleeder-divider resistor connected across the power-supply output performs three functions. As a bleeder, the resistor acts as a safety device to permit the filter capacitors to discharge when the equipment is turned off. As a load resistor, it acts as a stabilizer to protect the voltage regulator when no load is connected to the power supply and also helps to improve the regulation. As a voltage divider, it is tapped at various points along its length to provide intermediate values of the maximum voltage across the power-supply output. The bleeder-divider resistor can be grounded at the lower end, or it can be grounded at some point of higher potential along its length in order to provide negative voltage, or voltages, between the grounded point and B minus of the power supply. In item E, three positive outputs and one negative output (−40 volts) are obtained. Their polarities are shown with relation to ground. Amplifiers use power supplies to provide high voltage DC. The next section utilizes the power supply in explaining circuit operation.

22. Amplifier Circuits

22-1. In the earlier discussion of triodes, their importance in the development of tubes was pointed out. In the course of describing their construction, constants, and capacitance, you were told something about their operation. Now, let's get down to details. If the grid is connected directly to the cathode, as shown in figure 152, there will be no potential between the two elements. By applying a normal potential between the plate and cathode, the electron flow is affected only slightly, if at all, by the grid. As the diagram shows, the electrons are pulled across the tube by the positive plate potential. Only those moving directly toward a grid wire strike the grid, where they are deflected or captured. Those electrons that pass through the wire spaces enter the plate. You may recall that the attraction of the plate for an electron depends on the plate voltage and the distance between the plate and the electron source. The closer together the electron and the plate, the greater the attracting force. The same principle holds for the grid when it bears an electrical charge.

22-2. Suppose a small DC potential (bias) is connected between the grid and cathode, as shown in figure 153. Since the grid is much closer to the cathode than the plate, it will have more effect on the emitted electrons than the plate when voltage is applied to both these elements. As a matter of fact, this effect is so strong that a far greater voltage can be applied to the plate and the grid will still exercise more influence over the electrons.

22-3. If the grid were a solid plate, it would capture all the electrons, and the result would be a large current in the grid-cathode circuit. But since the grid is open, many of the electrons attracted to it actually pass through it. Thus, the electron flow to the plate is increased. Therefore, the more positive the grid becomes, the

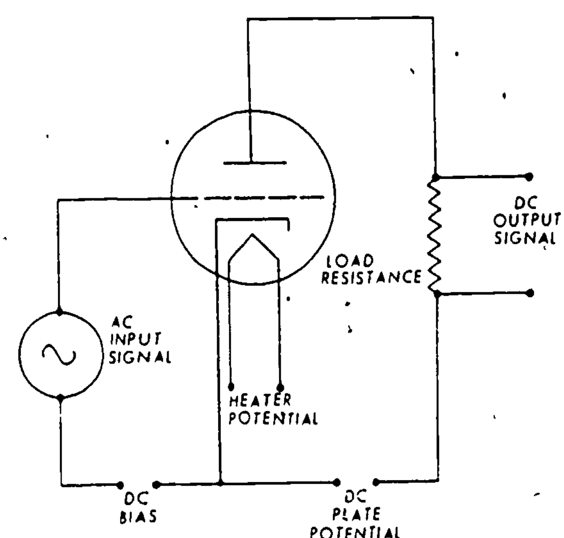

Figure 153. Simple amplifier circuit.

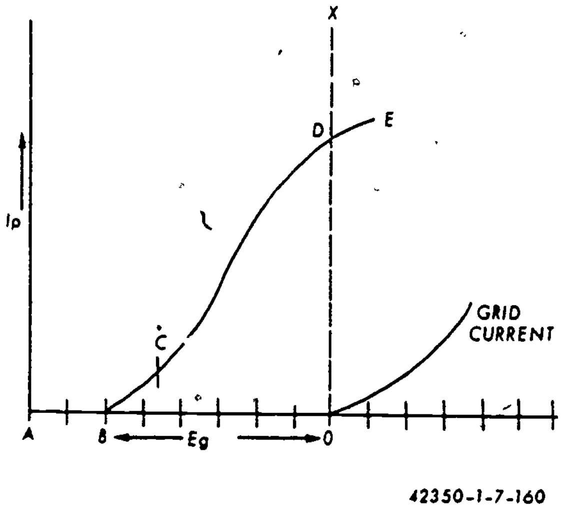

Figure 154. E_g–I_p curve.

more the plate current increases. Eventually, the grid attains a state of charge at which it begins to attract more electrons to itself. At that time, it begins to rob the plate of electrons. The result is a small but undesirable current flow in the grid-cathode circuit. However, there is a limit to the amount of increase in plate current that can be obtained by raising the positive charge on the control grid.

22-4. Let's assume that the potential on the grid is reversed. This element will now repel electrons. If the negative voltage becomes great enough, all electron movement between the cathode and plate will cease. However, if the grid becomes only slightly negative, the plate current will decrease accordingly.

22-5. You can readily see that a voltage applied to the grid will control the plate current. Moreover, such a voltage can also be used to vary it. If an AC signal voltage is applied between the grid and cathode, the alternate positive and negative half-cycles will produce up and down variations in the plate current. You are not looking for plate current variations, however, but for an amplified signal voltage. This can be obtained by simply connecting a load resistor in the plate circuit, as was shown previously in figure 153. This arrangement forces varying plate current to flow through the load resistor, and the resulting voltage drop across it will vary with the current. Thus, each time that the grid signal voltage varies, there is a change in both the plate current and the voltage across the load resistor. In other words, a signal voltage fed onto the grid is reproduced as a similar voltage across the load resistor; none of the plate current comes from the signal source. The grid signal voltage merely controls the flow of current from the power supply through the tube. You may find it easier to remember this action if you recall that it was mentioned earlier that the grid is a kind of electrical valve.

22-6. But, is this what you want in the voltage developed across the load resistor? Remember, you started out with the idea of using a tube to amplify a small grid or signal voltage. Your desire was to produce a voltage that would have the same general form as the signal voltage but would be considerably larger in magnitude. Let's find out, then, if it is larger. Ohm's law states that the voltage drop across the resistor is equal to the current flowing through it, multiplied by its resistance, or $E = I \times R$. From the equation, you can see that when R is large, even a fairly small plate current through it results in a large voltage drop. By the same token, a small *change* in plate current provides a big *change* in the voltage drop.

22-7. When you combine this information with the fact that a small change in grid voltage will produce a considerable one in plate current, you can see that it doesn't take much of a signal voltage change to cause a large one across the plate load resistor. Thus, by using this resistor, the signal voltage is amplified.

22-8. **Grid Voltage, Plate Current Curve.** There are restrictions that must be placed on the operation of triodes. For one thing, the amount of signal that can be applied to the grid is limited. If it is too great, the resulting changes in the plate current will not be carbon copies of the applied signal; and the output may be distorted. This is not too much of a problem when handling small signals, but after several stages of amplification the signal builds up to such proportions that tubes capable of handling large grid voltage variations must be used. To understand these limits better, study the E_g–I_p curve, shown in figure 154, which shows the relationships between the grid voltage and the plate current.

22-9. The shape of the typical E_g–I_p curve is quite similar to that of the other curves already mentioned. Since it has both positive and negative values of grid voltage, you must insert the vertical line OX to represent zero grid voltage. The distance along the horizontal reference line to the left of OX indicates increasingly negative grid voltage values, and the distance to the right, positive values. When there is a highly negative grid voltage (distance from OX to point A), there is no plate current. Assume that this negative voltage is gradually reduced. When the value represented by point B is reached, plate current will flow. (The E_g–I_p curve begins here.) The *cutoff* point is B, because it indicates the nega-

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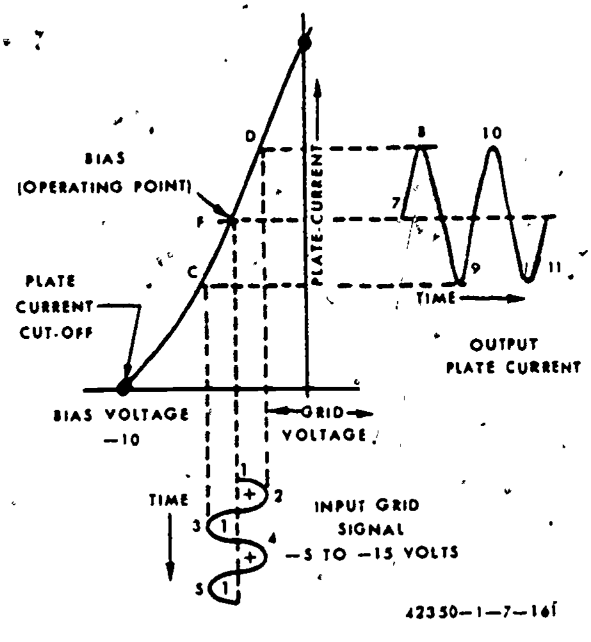

Figure 155. Grid signal variation-plate current (class A amplifier).

tive grid voltage which cancels the effects of the plate voltage. Any grid voltage that is more negative than this will "cut off" the plate current. As this voltage becomes less negative, the plate current will mount. Once the bend or "knee" of the curve (point C) has been reached, the plate current increases almost in step with the grid voltage change, and the curve will approach a straight line between points C and D. As the zero grid bias line (OX) is passed and the grid becomes increasingly more positive, the curve begins to flatten out toward point E. At the same time, the grid begins to attract electrons to itself. As pointed out earlier, the grid current increases steadily as it becomes more positive, and the grid now robs the stream and reduces the number of electrons that might be expected to go to the plate. In amplification, grid current is generally not needed; therefore, the tube must be prevented from operating on the upper *curved* part of its characteristic curve. If exact duplication of the signal voltage is desired, the tube must operate in the straight-line portion of the curve. To have the tube function near the middle of the straight portion, grid bias must be used.

22-10. **Grid Bias.** Earlier the term "bias" was mentioned several times. Now it is necessary to take up the subject in detail. In a moment, you will find out how grid bias is used. First, let's discuss its purpose. With grid bias, the development of a grid current is avoided by keeping the grid negative at all times. This is done by connecting the DC voltage between it and the cathode, as pointed out in figure 153. The word "bias" is used for the DC voltage that influences the initial operating plate current. The explanation should make this clear. A bias voltage which causes the tube to operate at point F on the curve shown in figure 155 sets the initial plate current at some particular value. After point F has been established, an AC signal voltage can be applied to the grid. This signal alternately adds to or subtracts from the grid bias voltage, making it successively more or less negative. If the bias voltage is −10 volts and the applied AC signal has a peak of 5 volts, the grid voltage will change alternately from −5 to −15 volts. The grid

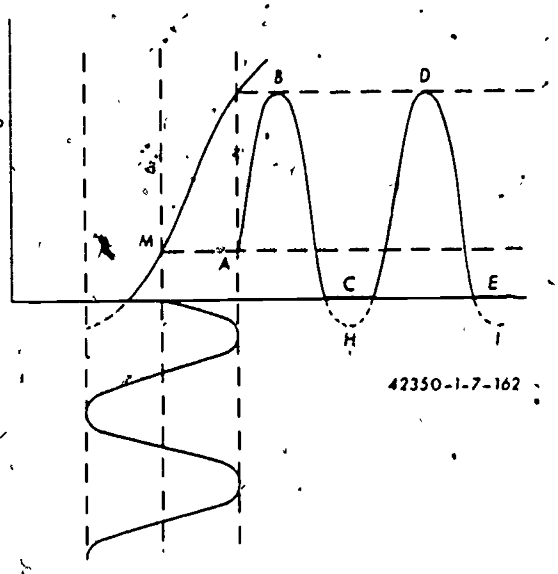

Figure 156. Excessive signal voltage distortion.

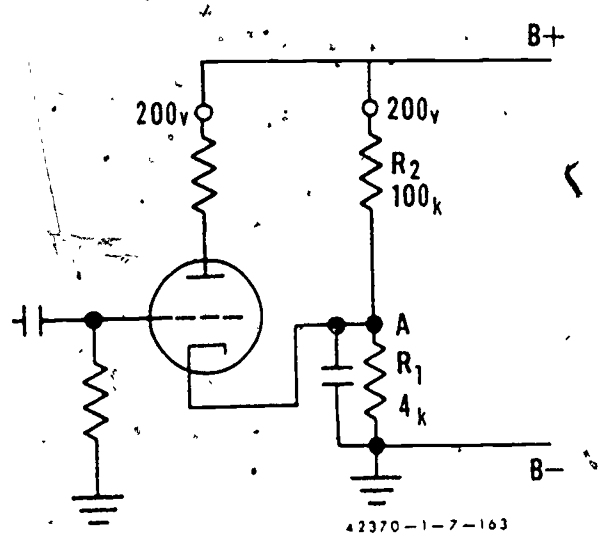

Figure 157. Fixed bias.

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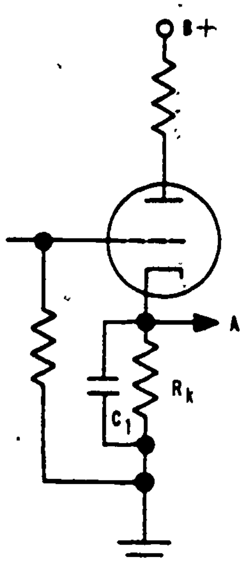

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Figure 158. Cathode bias.

voltage then becomes a pulsating DC because it is a mixture of DC and AC. As shown in figure 155, these changes in grid voltage cause alternate increases and decreases in plate current. The point F represents the operating point of the tube as set up by the bias voltage. When the grid voltage is varied by the AC signal (1–2–3–4–5), the operating point must follow the instantaneous grid voltage up and down the curve between points C and D. Thus, when the grid bias is reduced by the signal swing from 1 to 2, the grid becomes less negative and the operating point moves from F to D, permitting an increase in plate current from 7 to 8. Similarly, during the swing from 2 to 3 the grid becomes more negative, and the operating point goes from D to C, resulting in the plate current falling from 8 to 9. Hence, the AC grid voltage (1–2–3–4–5) produces the plate current variation (7–8–9–10–11). If the bias voltage changes during the operation, so will the plate current, and variations will occur that are not the result of the original signal. Therefore, to prevent this, a steady DC voltage has to be furnished so that these variations will be caused only by the signal voltage.

22-11. As long as the tube operates along the straight line portion of its characteristic curve and the AC voltage applied to the grid is not large enough to make the grid positive, the plate current variation will produce a voltage across the load resistor that is similar in form to the grid signal voltage. As you know, excessively high signal voltages or operation over a curved portion of the characteristic curve will result in distortion. For example, in figure 156 the grid bias is overly negative and, therefore, causes operating point M to fall too close to the lower bend. The curvature reveals how the bottoms of the plate current pulses are chopped off, thereby giving the distorted A–B–C–D–E curve. For exact reproduction of the grid signal plate, the current would have to follow the A–B–H–D–I curve.

22-12. Now that you are familiar with the term "bias," let us examine some of the methods used to provide bias voltage.

22-13. *Fixed bias*. Figure 157 illustrates one method of obtaining bias, which is through a voltage divider network in the cathode circuit. This is referred to as *fixed bias* and establishes the initial plate current. To explain this method, let us assume that point A in the illustration is at a potential of 7 volts. Since the grid is at ground potential assuming no grid current flow, the bias on the tube is also 7 volts. Under these conditions, when the tube conducts because of a grid signal, additional bias will result from the I_pR_1 drop.

22-14. *Cathode bias*. Another method of providing bias is called *cathode bias*, or self-bias. As shown in figure 158, a resistor has been placed in the cathode circuit. As the tube conducts, there will be current flow across R_k. Point A will be at a positive potential with respect to ground because of the IR drop across resistor R_k. Since the grid is at ground potential, the cathode is positive with respect to the grid, or the grid will be negative with respect to the cathode. The amount of bias on the tube is equal to the IR drop across R_k. Any change in current flow through the tube will change the bias. To stabi-

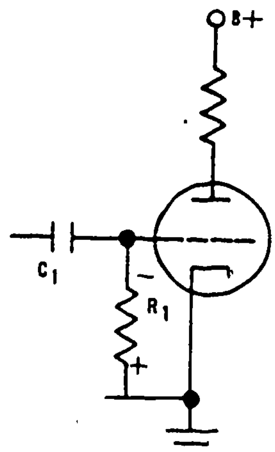

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Figure 159. Grid-leak bias.

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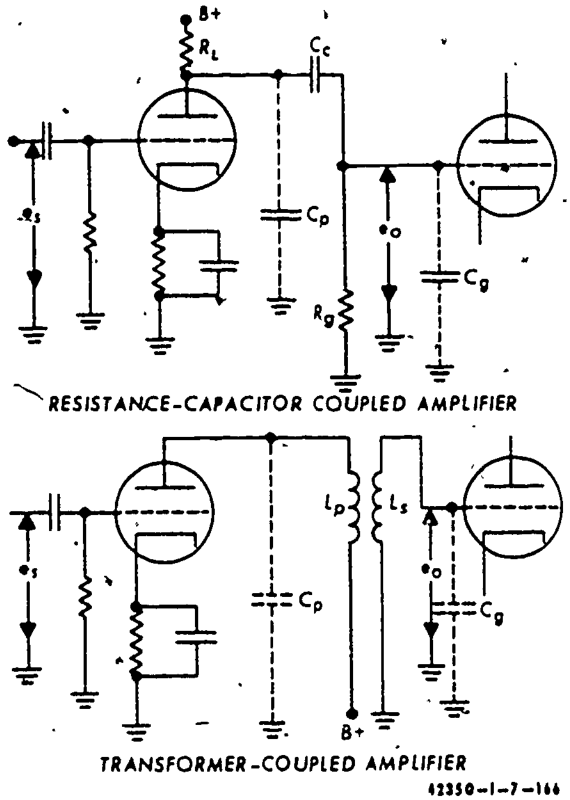

Figure 160. Types of coupling for triode amplifiers.

lize the bias voltage, a filter capacitor (C_1) is placed in parallel across the cathode resistor.

22-15. *Grid-leak bias.* A third method of obtaining bias voltage is called *grid-leak bias.* This method is shown in figure 159. If an alternating current is applied to the grid, the grid will become positive with respect to the cathode during the positive half-cycle, and some electrons will pass from the cathode to the grid. In other words, grid current will flow and capacitor C_1 will charge. Capacitor C_1 will tend to charge very rapidly, because when the grid draws current the grid-to-cathode resistance of the tube drops to a very low value (usually about 1000 ohms).

22-16. On the negative half-cycle of the applied alternating current, capacitor C_1 attempts to discharge through resistor R_1. Resistor R_1 is usually a large-valued resistor, between 500 K and 1 megohm, which means that the discharge rate of C_1 will be slower than its charge rate. Thus, the grid is *negative* in respect to the cathode which is at ground *potential,* and *bias* is established.

22-17. **Coupling.** When one stage of amplification (a tube and its circuit connections) is coupled to the next, the plate cannot be connected directly to the grid of the following stage. Instead, a special circuit is used. The coupling circuit transfers the AC signal voltage between the stages while isolating the DC plate voltage from the grid of the following tube. There are two primary methods by which amplifier stages are coupled together, the *resistance-capacitance* and *transformer* types, both of which are shown in figure 160.

22-18. *Resistance-capacitance coupling.* In the resistance-capacitance (or simply the RC-coupled) amplifier, the biased cathode shown in the figure is the most commonly used. For the grid of the second stage, the coupling capacitor (C_c) provides a low-impedance path, and the resistor (R_L) furnishes high enough resistance to permit

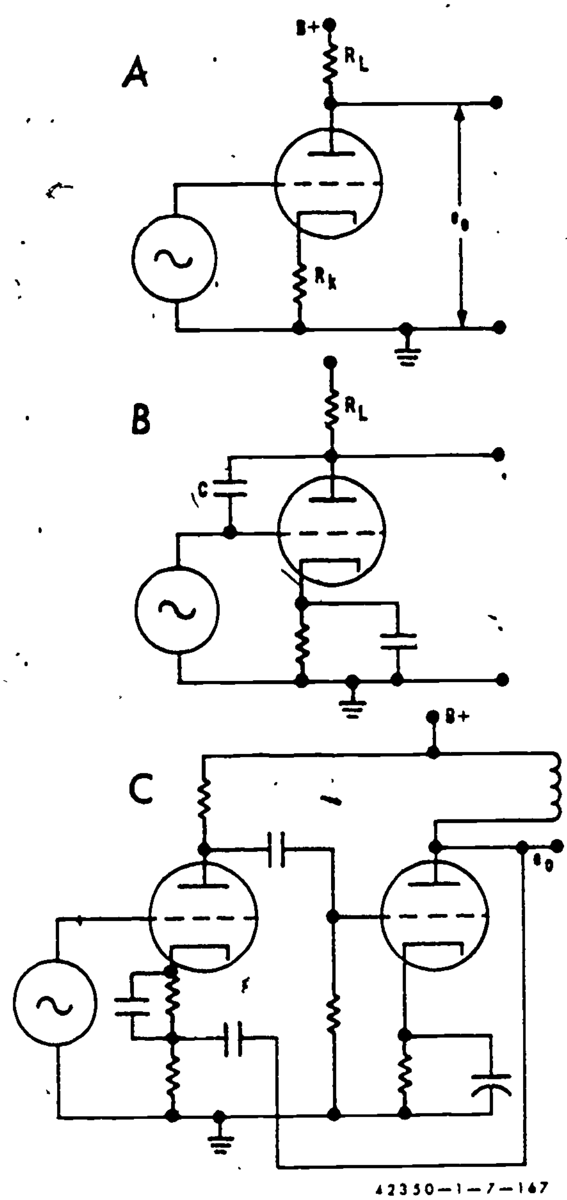

Figure 161. Methods of obtaining feedback.

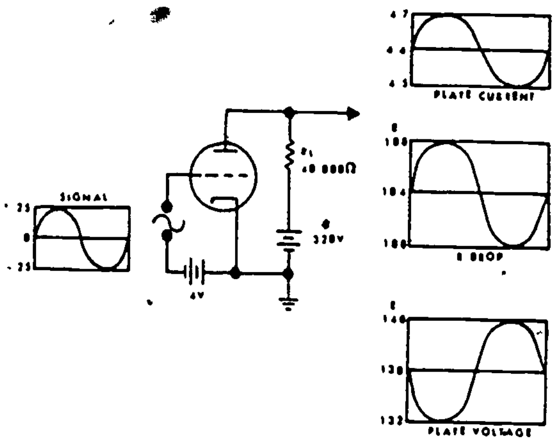

Figure 162. Class A amplifier operation.

as much voltage as possible to be transferred there.

22-19. The coupling between the two stages takes place in the following manner. When a signal is applied to the grid of the first stage, voltage variations in the plate circuit are impressed upon the grid of the second tube through the coupling capacitor and the grid resistor (R_g).

22-20. The coupling capacitor, in addition to providing a path for AC to reach the grid of the following tube, also prevents the plate voltage of the first tube from reaching the grid of the second one.

22-21. *Transformer coupling.* Although not as common as the resistance-capacitance type, the transformer method is often used to couple amplifier stages. In the transformer circuit, shown in figure 160, current from the plate of the tube in the first stage flows through the primary (L_p) and causes a voltage. This is induced into the secondary (L_s), to be applied to the grid of the second tube as a signal. The overall effect is that the amplified signal of the first stage is transferred by the transformer to the grid of the second stage, where further amplification takes place.

22-22. Just as important to amplifiers as coupling is feedback. We have already pointed out several ways of controlling feedback. However, a more interesting aspect of the topic concerns the way we can use it to aid amplification.

22-23. **Feedback in Amplifiers.** Sometimes a portion of the amplified output energy is fed back into the input circuit. If this feedback aids the signal, it is called *positive* or *regenerative;* if the portion is fed back to oppose the input voltage, the feedback is called *degenerative, negative,* or *inverse.*

22-24. Feedback can be obtained in several ways, as shown in figure 161. In the first diagram (part A) feedback voltage is developed across the cathode resistor (R_k), which is not bypassed as a result of the plate current flowing through it. This voltage varies at the same rate as that of the plate. Since R_k is located between the grid and cathode, any voltage developed across it is in series with the input signal of the tube. This condition establishes a phase relation suitable for degeneration. Thus, when a positive signal appears on the grid, both the plate current and the voltage drop across R_k increase. A voltage increase across the cathode resistor makes the grid more negative with relation to the cathode, which is opposite to the action provided by the signal voltage. This arrangement is useful in canceling distortion in the output signal determined from the E_g–I_p characteristic curve. Since plate voltage changes in a tube do not duplicate those of the grid voltage, there is some distortion in the output wave shape. However, degenerative feedback introduces a portion of the distorted output into the input in reverse, thereby counterbalancing the conditions that cause the original distortion.

22-25. You also can get feedback by connecting a capacitor from the plate to the grid, as shown in part B of figure 161. Here the plate voltage changes produced by plate current variations are opposite in polarity to the original grid voltage changes. The capacitor introduces a small part of the plate voltage change into the grid circuit. This reflects the *distortion* in the plate current in reverse, and thus virtually cancels the distortion previously existing in the output.

22-26. Feedback can be used effectively in multistage amplifiers (see part C in figure 161). Not only is it useful for counteracting the effects of distortion introduced by the tubes, but it can also aid in eliminating out-of-phase relationships caused by certain circuit components. For example, feedback compensates for any changes in

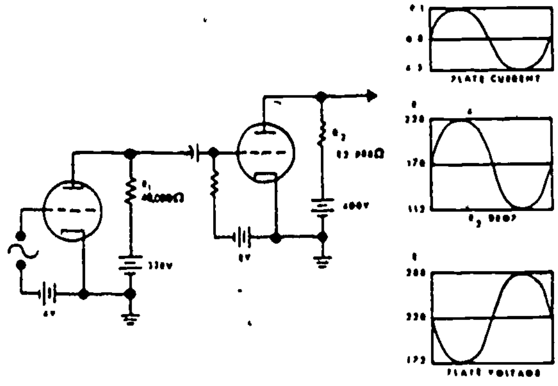

Figure 163. Capacitor-coupled second stage of amplifier.

the inductive reactance of the deflection coil in the circuit. When current flows through this coil, its reactance changes and alters the plate voltage. In turn, this alteration moves around the feedback loop and counteracts the inductance change. This action makes the plate voltage normal and insures an undistorted output.

22-27. In some circuits, reactance elements send positive feedback into the circuit and cause it to oscillate. This condition is all right in oscillators but not in amplifiers. Therefore, a type of feedback arrangement similar to that in the two-stage feedback amplifier must be used to introduce a negative feedback into the input to cancel the effects of the regeneration.

22-28. The discussion of electron tube and amplifier circuits is not finished. Although many other tube circuits could have been presented, only those relevant to your work on aircraft electrical installations have been discussed. Know these circuits completely, and your job will be greatly simplified.

22-29. **Applying Definite Signals to an Amplifier.** By studying the application of a small signal voltage to the grid and by observing the highly amplified voltage change it causes in the plate output circuit, it is easy to see how an amplifier works. The following discussion deals with a simple class A amplifier, such as that shown in figure 162, and a capacitor-coupled class A amplifier, such as that shown in figure 163. Using the diagram in figure 162, let's determine the plate voltage and current values.

22-30. Assuming that R_1 is 40,000 ohms and plate potential is 320 volts, when grid voltage varies from -4.25 to -3.75 volts, plate output voltage will vary from 132 to 140 volts. This is evidenced by comparing the grid voltage, R_1 voltage drop, plate output voltage, and current sine waves in figure 162. According to the sine waves, when grid voltage is -4 volts, plate current will be 4.6 milliamperes. This means that the voltage drop across R_1 will be 184 volts. This can be proved by applying Ohm's law.

$$\begin{aligned} E &= I \times R \\ &= 40{,}000 \times 0.0046 \\ &= 184 \text{ v} \end{aligned}$$

Therefore, since plate potential is 320 volts and 184 volts is lost across R_1, plate output voltage will be 136 volts.

22-31. When grid voltage goes to -3.75 volts, plate current will go to 4.7 milliamperes. This means that the voltage drop across R_1 has increased to 188 volts; therefore, plate output voltage will be 132 volts. Remember, the reason for the increase in plate current is the fact that the control grid has become more positive, which allows more current to flow.

22-32. Now suppose the grid voltage is driven to -4.25 volts. This will cause plate current to decrease to 4.5 milliamperes. Using Ohm's law once again, you will find that the voltage drop across R_1 is 180 volts, which means that plate output voltage will increase to 140 volts.

22-33. From the preceding discussion you should be able to understand better how amplification is accomplished. Suppose another tube is added in series with the first. Now the plate of the first tube is connected to the grid of the second, as seen in figure 163. For the purpose of illustration, let's use the simple capacitor-coupled amplifier in figure 163.

22-34. With a 4-volt variation in grid signal (above and below the -8-volt bias), the grid will be -4 volts during one alternation and -12 volts during the other. By comparing the sine waves as before, you can see the greater amplification in the second stage. As the grid signal reaches -4 volts, the drop across R_2 will be 228 volts and the plate output will be 172 volts. When the grid signal reaches -12 volts, the drop across R_2 will be 112 and plate output will be 288 volts. The plate current will vary from 4.5 milliamps to 9.1 milliamps as the voltage varies throughout the circuit. As seen in the drawing, the 4-volt variation in the first stage causes a 58-volt variation in the second stage.

22-35. This concludes our discussion of the electron tube and its application. By now you should be able to troubleshoot tube type circuits. Compare this information to other tube type circuits with which you may be working.

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APPENDIXES

APPENDIX A

Squares and Square Roots

n	n^2	$\sqrt{n}$	$\sqrt{10n}$	n	n^2	$\sqrt{n}$	$\sqrt{10n}$
1	1	1.000	3.162	51	2601	7.141	22.583
2	4	1.414	4.472	52	2704	7.211	22.804
3	9	1.732	5.477	53	2809	7.280	23.022
4	16	2.000	6.325	54	2916	7.349	23.238
5	25	2.236	7.071	55	3025	7.416	23.452
6	36	2.449	7.746	56	3136	7.483	23.664
7	49	2.646	8.367	57	3249	7.550	23.875
8	64	2.828	8.944	58	3364	7.616	24.083
9	81	3.000	9.487	59	3481	7.681	24.290
10	100	3.162	10.000	60	3600	7.746	24.495
11	121	3.317	10.488	61	3721	7.810	24.698
12	144	3.464	10.954	62	3844	7.874	24.900
13	169	3.606	11.402	63	3969	7.937	25.100
14	196	3.742	11.832	64	4096	8.000	25.298
15	225	3.873	12.247	65	4225	8.062	25.495
16	256	4.000	12.649	66	4356	8.124	25.690
17	289	4.123	13.038	67	4489	8.185	25.884
18	324	4.243	13.416	68	4624	8.246	26.077
19	361	4.359	13.784	69	4761	8.307	26.268
20	400	4.472	14.142	70	4900	8.367	26.458
21	441	4.583	14.491	71	5041	8.426	26.646
22	484	4.690	14.832	72	5184	8.485	26.833
23	529	4.796	15.166	73	5329	8.544	27.019
24	576	4.899	15.492	74	5476	8.602	27.203
25	625	5.000	15.811	75	5625	8.660	27.386
26	676	5.099	16.125	76	5776	8.718	27.568
27	729	5.196	16.432	77	5929	8.775	27.749
28	784	5.292	16.733	78	6084	8.832	27.928
29	841	5.385	17.029	79	6241	8.888	28.107
30	900	5.477	17.321	80	6400	8.944	28.284
31	961	5.568	17.607	81	6561	9.000	28.461
32	1024	5.657	17.889	82	6724	9.055	28.636
33	1089	5.745	18.166	83	6889	9.110	28.810
34	1156	5.831	18.439	84	7056	9.165	28.983
35	1225	5.916	18.708	85	7225	9.220	29.155
36	1296	6.000	18.974	86	7396	9.274	29.326
37	1369	6.083	19.235	87	7569	9.327	29.496
38	1444	6.164	19.494	88	7744	9.381	29.665
39	1521	6.245	19.748	89	7921	9.434	29.833
40	1600	6.325	20.000	90	8100	9.487	30.000
41	1681	6.403	20.248	91	8281	9.540	30.166
42	1764	6.481	20.494	92	8464	9.592	30.332
43	1849	6.557	20.736	93	8649	9.644	30.496
44	1936	6.633	20.976	94	8836	9.695	30.659
45	2025	6.708	21.213	95	9025	9.747	30.822
46	2116	6.782	21.448	96	9216	9.798	30.984
47	2209	6.856	21.679	97	9409	9.849	31.145
48	2304	6.928	21.909	98	9604	9.900	31.305
49	2401	7.000	22.136	99	9801	9.950	31.464
50	2500	7.071	22.361	100	10000	10.000	31.623

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APPENDIX B

Natural Sines, Cosines, and Tangents

Angles	Sines Nat.	Sines Log.	Cosines Nat.	Cosines Log.	Tangents Nat.	Tangents Log.	Cotangents Nat.	Cotangents Log.	Angle
0° 00′	.0000	∞	1.0000	0.0000	.0000	∞	∞	∞	90° 00′
10	.0029	7.4637	1.0000	0000	.0029	7.4637	343.77	2.5363	50
20	.0058	7648	1.0000	0000	.0058	7648	171.89	2352	40
30	.0087	9408	1.0000	0000	.0087	9409	114.59	0591	30
40	.0116	8.0658	.9999	0000	.0116	8.0658	85.940	1.9342	20
50	.0145	1627	.9999	0000	.0145	1627	68.750	8373	10
1° 00′	.0175	8.2419	.9908	9.9999	.0175	8.2419	57.290	1.7581	89° 00′
10	.0204	3088	.9998	9909	.0204	3089	49.104	6911	50
20	.0233	3068	.9997	9909	.0233	3669	42.964	6331	40
30	.0262	4179	.9997	9909	.0262	4181	38.188	5819	30
40	.0291	4637	.9996	9098	.0291	4638	34.368	5362	20
50	.0320	5050	.9995	9998	.0320	5053	31.242	4947	10
2° 00′	.0349	8.5428	.9994	9.9997	.0349	8.5431	28.636	1.4569	88° 00′
10	.0378	5776	.9993	9997	.0378	5779	26.432	4221	50
20	.0407	6097	.9992	9996	.0407	6101	24.542	3899	40
30	.0436	6397	.9900	9996	.0437	6401	22.904	3599	30
40	.0465	6677	.9989	9995	.0466	6682	21.470	3318	20
50	.0494	6940	.9988	9995	.0495	6945	20.206	3055	10
3° 00′	.0523	8.7188	.9986	9.9994	.0524	8.7194	19.081	1.2806	87° 00′
10	.0552	7423	.9985	9993	.0553	7429	18.075	2571	50
20	.0581	7645	.9983	9093	.0582	7652	17.169	2348	40
30	.0610	7857	.9081	9992	.0612	7865	16.350	2135	30
40	.0640	8059	.9980	9991	.0641	8067	15.605	1933	20
50	.0669	8251	.9978	9990	.0670	8261	14.924	1739	10
4° 00′	.0698	8.8436	.9976	9.9989	.0699	8.8446	14.301	1.1554	86° 00′
10	.0727	8613	.9974	9989	.0729	8624	13.727	1376	50
20	.0756	8783	.9971	9988	.0758	8795	13.197	1205	40
30	.0785	8946	.9969	9987	.0787	8960	12.706	1040	30
40	.0814	9104	.9967	9986	.0816	9118	12.251	0882	20
50	.0843	9256	.9964	9985	.0846	9272	11.826	0728	10
5° 00′	.0872	8.9403	.9962	9.9983	.0875	8.9420	11.430	1.0580	85° 00′
10	.0901	9545	.9959	9982	.0904	9563	11.059	0437	50
20	.0929	9682	.9957	9981	.0934	9701	10.712	0299	40
30	.0958	9816	.9954	9980	.0963	9836	10.385	0164	30
40	.0987	9945	.9951	9979	.0992	9966	10.078	0034	20
50	.1016	9.0070	.9948	9977	.1022	9.0093	9.7882	0.9907	10
6° 00′	.1045	9.0192	.9945	9.9976	.1051	9.0216	9.5144	0.9784	84° 00′
10	.1074	0311	.9942	9975	.1080	0336	9.2553	9664	50
20	.1103	0426	.9939	9973	.1110	0453	9.0098	9547	40
30	.1132	0539	.9936	9972	.1139	0567	8.7769	9433	30
40	.1161	0648	.9932	9971	.1169	0678	8.5555	9322	20
50	.1190	0755	.9929	9969	.1198	0786	8.3450	9214	10
7° 00′	.1219	9.0859	.9925	9.9968	.1228	9.0891	8.1443	0.9109	83° 00′
10	.1248	0961	.9922	9966	.1257	0995	7.9530	9005	50
20	.1276	1060	.9918	9964	.1287	1096	7.7704	8904	40
30	.1305	1157	.9914	9963	.1317	1194	7.5958	8806	30
40	.1334	1252	.9911	9961	.1346	1291	7.4287	8709	20
50	.1363	1345	.9907	9959	.1376	1385	7.2687	8615	10
8° 00′	.1392	9.1436	.9903	9.9958	.1405	9.1478	7.1154	0.8522	82° 00′
10	.1421	1525	.9809	9956	.1435	1569	6.9682	8431	50
20	.1449	1612	.9894	9954	.1465	1658	6.8269	8342	40
30	.1478	1697	.9890	9952	.1495	1745	6.6912	8255	30
40	.1507	1781	.9886	9950	.1524	1831	6.5606	8169	20
50	.1536	1863	.9881	9948	.1554	1915	6.4348	8085	10
9° 00′	.1564	9.1943	.9877	9.9946	.1584	9.1997	6.3138	0.8003	81° 00′
Angles	Cosines Nat.	Cosines Log.	Sines Nat.	Sines Log.	Cotangents Nat.	Cotangents Log.	Tangents Nat.	Tangents Log.	Angles

Angles	Sines Nat.	Sines Log.	Cosines Nat.	Cosines Log.	Tangents Nat.	Tangents Log.	Cotangents Nat.	Cotangents Log.	Angles
9° 00′	.1564	9.1943	.9877	9.9946	.1584	9.1997	6.3138	0.8003	81° 00′
10	.1593	2022	.9872	9944	.1614	2078	6.1970	7922	50
20	.1622	2100	.9868	9942	.1644	2158	6.0844	7842	40
30	.1650	2176	.9863	9940	.1673	2236	5.9758	7764	30
40	.1679	2251	.9858	9938	.1703	2313	5.8708	7687	20
50	.1708	2324	.9853	9936	.1733	2389	5.7694	7611	10
10° 00′	.1736	9.2397	.9848	9.9934	.1763	9.2463	5.6713	0.7537	80° 00′
10	.1765	2468	.9843	9931	.1793	25[illegible]6	5.5764	7464	50
20	.1794	2538	.9838	9929	.1823	2609	5.4845	7391	40
30	.1822	2606	.9833	9927	.1853	2680	5.3955	7320	30
40	.1851	2674	.9827	9924	.1883	2750	5.3093	7250	20
50	.1880	2740	.9822	9922	.1914	2819	5.2257	7181	10
11° 00′	.1908	9.2806	.9816	9.9919	.1944	9.2887	5.1446	0.7113	79° 00′
10	.1937	2870	.9811	9917	.1974	2953	5.0658	7047	50
20	.1965	2934	.9805	9914	.2004	3020	4.9894	6980	40
30	.1904	2997	.9799	9912	.2035	3085	4.9152	6915	30
40	.2022	3058	.9793	9909	.2065	3149	4.8430	6851	20
50	.2051	3119	.9787	9907	.2095	3212	4.7729	6788	10
12° 00′	.2079	9.3179	.9781	9.9904	.2126	9.3275	4.7046	0.6725	78° 00′
10	.2108	3238	.9775	9901	.2156	3336	4.6382	6664	50
20	.2136	3296	.9769	9899	.2186	3397	4.5736	6603	40
30	.2164	3353	.9763	9896	.2217	3458	4.5107	6542	30
40	.2193	3410	.9757	9893	.2247	3517	4.4494	6483	20
50	.2221	3466	.9750	9890	.2278	3576	4.3897	6424	10
13° 00′	.2250	9.3521	.9744	9.9887	.2309	9.3634	4.3315	0.6366	77° 00′
10	.2278	3575	.9737	9884	.2339	3691	4.2747	6309	50
20	.2306	3629	.9730	9881	.2370	3748	4.2193	6252	40
30	.2334	3682	.9724	9878	.2401	3804	4.1653	6196	30
40	.2363	3734	.9717	9875	.2432	3859	4.1126	6141	20
50	.2391	3786	.9710	9872	2462	3914	4.0611	6086	10
14° 00′	.2419	9.3837	.9703	9.9869	.2493	9.3968	4.0108	0.6032	76° 00′
10	.2447	3887	.9696	9866	.2524	4021	3.9617	5979	50
20	.2476	3937	.9689	9863	.2555	4074	3.9136	5926	40
30	.2504	3986	.9681	9859	.2586	4127	3.8667	5873	30
40	.2532	4035	.9674	9856	.2617	4178	3.8208	5822	20
50	.2560	4083	.9667	9853	.2648	4230	3.7760	5770	10
15° 00′	.2588	9.4130	.9659	9.9849	.2679	9.4281	3.7321	0.5719	75° 00′
10	.2616	4177	.9652	9846	.2711	4331	3.6891	5669	50
20	.2644	4223	.9644	9843	.2742	4381	3.6470	5619	40
30	.2672	4269	.9636	9839	.2773	4430	3.6059	5570	30
40	.2700	4314	.9628	9836	.2805	4479	3.5656	5521	20
50	.2728	4359	.9621	9832	.2836	4527	3.5261	5473	10
16° 00′	.2756	9.4403	.9613	9.9828	.2867	9.4575	3.4874	0.5425	74° 00′
10	.2784	4447	.9605	9825	.2899	4622	3.4495	5378	50
20	.2812	4491	.9596	9821	.2931	4669	3.4124	5331	40
30	.2840	4533	.9588	9817	.2962	4716	3.3759	5284	30
40	.2868	4576	.9580	9814	.2994	4762	3.3402	5238	20
50	.2896	4618	.9572	9810	.3026	4808	3.3052	5192	10
17° 00′	.2924	9.4659	.9563	9.9806	.3057	9.4853	3.2709	0.5147	73° 00′
10	.2952	4700	.9555	9802	.3089	4898	3.2371	5102	50
20	.2979	4741	.9546	9798	.3121	4943	3.2041	5057	40
30	.3007	4781	.9537	9794	.3153	4987	3.1716	5013	30
40	.3035	4821	.9528	9790	.3185	5031	3.1397	4969	20
50	.3062	4861	.9520	9786	.3217	5075	3.1084	4925	10
18° 00′	.3090	9.4900	.9511	9.9782	.3249	9.5118	3.0777	0.4882	72° 00′
	Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.	
Angles	Cosines		Sines		Cotangents		Tangents		Angles

APPENDIX B (Cont'd)

Angles	Sines		Cosines		Tangents		Cotangents		Angles
	Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.	
18° 00′	.3090	9.4900	.9511	9.9782	.3249	9.5118	3.0777	0.4882	72° 00′
10	.3118	4939	.9502	9778	.3281	5161	3.0475	4839	50
20	.3145	4977	.9492	9774	.3314	5203	3.0178	4797	40
30	.3173	5015	.9483	9770	.3346	5245	2.9887	4755	30
40	.3201	5052	.9474	9765	.3378	5287	2.9600	4713	20
50	.3228	5090	.9465	9761	.3411	5329	2.9319	4671	10
19° 00′	.3256	9.5126	.9455	9.9757	.3443	9.5370	2.9042	0.4630	71° 00′
10	.3283	5163	.9446	9752	.3476	5411	2.8770	4589	50
20	.3311	5199	.9436	9748	.3508	5451	2.8502	4549	40
30	.3338	5235	.9426	9743	.3541	5491	2.8239	4509	30
40	.3365	5270	.9417	9739	.3574	5531	2.7980	4469	20
50	.3393	5306	.9407	9734	.3607	5571	2.7725	4429	10
20° 00′	.3420	9.5341	.9397	9.9730	.3640	9.5611	2.7475	0.4389	70° 00′
10	.3448	5375	.9387	9725	.3673	56[illegible]0	2.7228	4350	50
20	.3475	5409	.9377	9721	.3706	5689	2.6985	4311	40
30	.3502	5443	.9367	9716	.3739	5727	2.6746	4273	30
40	.3529	5477	.9356	9711	.3772	5706	2.6511	4234	20
50	.3557	5510	.9346	9706	.3805	5804	2.6279	4196	10
21° 00′	.3584	9.5543	.9336	9.9702	.3839	9.5842	2.6051	0.4158	69° 00′
10	.3611	5576	.9325	9697	.3872	5879	2.5826	4121	50
20	.3638	5609	.9315	9692	.3906	5917	2.5605	4083	40
30	.3665	5641	.9304	9687	.3939	5954	2.5386	4046	30
40	.3692	5673	.9293	9682	.3973	5991	2.5172	4009	20
50	.3719	5704	.9283	9677	.4006	6028	2.4960	3972	10
22° 00′	.3746	9.5736	.9272	9.9672	.4040	9.6064	2.4751	0.3936	68° 00′
10	.3773	5767	.9261	9667	.4074	6100	2.4545	3900	50
20	.3800	5798	.9250	9661	.4108	6136	2.4342	3864	40
30	.3827	5828	.9239	9656	.4142	6172	2.4142	3828	30
40	.3854	5859	.9228	9651	.4176	6208	2.3945	3792	20
50	.3881	5889	.9216	9646	.4210	6243	2.3750	3757	10
23° 00′	.3907	9.5919	.9205	9.9640	.4245	9.6279	2.3559	0.3721	67° 00′
10	.3934	5948	.9194	9635	.4279	6314	2.3369	3686	50
20	.3961	5978	.9182	9629	.4314	6348	2.3183	3652	40
30	.3987	6007	.9171	9624	.4348	6383	2.2998	3617	30
40	.4014	6036	.9159	9618	.4383	6417	2.2817	3583	20
50	.4041	6065	.9147	9613	.4417	6452	2.2637	3548	10
24° 00′	.4067	9.6093	.9135	9.9607	.4452	9.6486	2.2460	0.3514	66° 00′
10	.4094	6121	.9124	9602	.4487	6520	2.2286	3480	50
20	.4120	6149	.9112	9596	.4522	6553	2.2113	3447	40
30	.4147	6177	.9100	9590	.4557	6587	2.1943	3413	30
40	.4173	6205	.9088	9584	.4592	6620	2.1775	3380	20
50	.4200	6232	.9075	9579	.4628	6654	2.1609	3346	10
25° 00′	.4226	9.6259	.9063	9.9573	.4663	9.6687	2.1445	0.3313	65° 00′
10	.4253	6286	.9051	9567	.4699	6720	2.1283	3280	50
20	.4279	6313	.9038	9561	.4734	6752	2.1123	3248	40
30	.4305	6340	.9026	9555	.4770	6785	2.0965	3215	30
40	.4331	6366	.9013	9549	.4806	6817	2.0809	3183	20
50	.4358	6392	.9001	9543	.4841	6850	2.0655	3150	10
26° 00′	.4384	9.6418	.8988	9.9537	.4877	9.6882	2.0503	0.3118	64° 00′
10	.4410	6444	.8975	9530	.4913	6914	2.0353	3086	50
20	.4436	6470	.8962	9524	.4950	6946	2.0204	3054	40
30	.4462	6495	.8949	9518	.4986	6977	2.0057	3023	30
40	.4488	6521	.8936	9512	.5022	7009	1.9912	2991	20
50	.4514	6546	.8923	9505	.5059	7040	1.9768	2960	10
27° 00′	.4540	9.6570	.8910	9.9499	.5095	9.7072	1.9626	0.2928	63° 00′
	Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.	
Angles	Cosines		Sines		Cotangents		Tangents		Angles

APPENDIX B (Cont'd)

Angles	Sines		Cosines		Tangents		Cotangents		Angles
	Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.	
27° 00′	.4540	9.6570	.8910	9.9499	.5095	9.7022	1.9626	0.2928	63° 00′
10	.4566	6595	.8897	9492	.5132	7103	1.9486	2897	50
20	.4592	6620	.8884	9486	.5169	7134	1.9347	2866	40
30	.4617	6644	.8870	9479	.5206	7165	1.9210	2835	30
40	.4643	6668	.8857	9473	.5243	7196	1.9074	2804	20
50	.4669	6692	.8843	9466	.5280	7226	1.8940	2774	10
28° 00′	.4695	9.6716	.8829	9.9459	.5317	9.7257	1.8807	0.2743	62° 00′
10	.4720	6740	.8816	9453	.5354	7287	1.8676	2713	50
20	.4746	6763	.8802	9446	.5392	7317	1.8546	2683	40
30	.4772	6787	.8788	9439	.5430	7348	1.8418	2652	30
40	.4797	6810	.8774	9432	.5467	7378	1.8291	2622	20
50	.4823	6833	.8760	9425	.5505	7408	1.8165	2592	10
29° 00′	.4848	9.6856	.8746	9.9418	.5543	9.7438	1.8040	0.2562	61° 00′
10	.4874	6878	.8732	9411	.5581	7467	1.7917	2533	50
20	.4899	6901	.8718	9404	.5619	7497	1.7796	2503	40
30	.4924	6923	.8704	9397	.5658	7526	1.7675	2474	30
40	.4950	6946	.8689	9390	.5696	7556	1.7556	2444	20
50	.4975	6968	.8675	9383	.5735	7585	1.7437	2415	10
30° 00′	.5000	9.6990	.8660	9.9375	.5774	9.7614	1.7321	0.2386	60° 00′
10	.5025	7012	.8646	9368	.5812	7644	1.7205	2356	50
20	.5050	7033	.8631	9361	.5851	7673	1.7090	2327	40
30	.5075	7055	.8616	9353	.5890	7701	1.6977	2299	30
40	.5100	7076	.8601	9346	.5930	7730	1.6864	2270	20
50	.5125	7097	.8587	9338	.5969	7759	1.6753	2241	10
31° 00′	.5150	9.7118	.8572	9.9331	.6009	9.7788	1.6643	0.2212	59° 00′
10	.5175	7139	.8557	9323	.6048	7816	1.6534	2184	50
20	.5200	7160	.8542	9315	.6088	7845	1.6426	2155	40
30	.5225	7181	.8526	9308	.6128	7873	1.6319	2127	30
40	.5250	7201	.8511	9300	.6168	7902	1.6212	2098	20
50	.5275	7222	.8496	9292	.6208	7930	1.6107	2070	10
32° 00′	.5299	9.7242	.8480	9.9284	.6249	9.7958	1.6003	0.2042	58° 00′
10	.5324	7262	.8465	9276	.6289	7986	1.5900	2014	50
20	.5348	7282	.8450	9268	.6330	8014	1.5798	1986	40
30	.5373	7302	.8434	9260	.6371	8042	1.5697	1958	30
40	.5398	7322	.8418	9252	.6412	8070	1.5597	1930	20
50	.5422	7342	.8403	9244	.6453	8097	1.5497	1903	10
33° 00′	.5446	9.7361	.8387	9.9236	.6494	9.8125	1.5399	0.1875	57° 00′
10	.5471	7380	.8371	9228	.6536	8153	1.5301	1847	50
20	.5495	7400	.8355	9219	.6577	8180	1.5204	1820	40
30	.5519	7419	.8339	9211	.6619	8208	1.5108	1792	30
40	.5544	7438	.8323	9203	.6661	8235	1.5013	1765	20
50	.5568	7457	.8307	9194	.6703	8263	1.4919	1737	10
34° 00′	.5592	9.7476	.8290	9.9186	.6745	9.8290	1.4826	0.1710	56° 00′
10	.5616	7494	.8274	9177	.6787	8317	1.4733	1683	50
20	.5640	7513	.8258	9169	.6830	8344	1.4641	1656	40
30	.5664	7531	.8241	9160	.6873	8371	1.4550	1629	30
40	.5688	7550	.8225	9151	.6916	8398	1.4460	1602	20
50	.5712	7568	.8208	9142	.6959	8425	1.4370	1575	10
35° 00′	.5736	9.7586	.8192	9.9134	.7002	9.8452	1.4281	0.1548	55° 00′
10	.5760	7604	.8175	9125	.7046	8479	1.4193	1521	50
20	.5783	7622	.8158	9116	.7089	8506	1.4106	1494	40
30	.5807	7640	.8141	9107	.7133	8533	1.4019	1467	30
40	.5831	7657	.8124	9098	.7177	8559	1.3934	1441	20
50	.5854	7675	.8107	9089	.7221	8586	1.3848	1414	10
36° 00′	.5878	9.7692	.8090	9.9080	.7265	9.8613	1.3764	0.1387	54° 00′
	Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.	
Angles	Cosines		Sines		Cotangents		Tangents		Angles

APPENDIX B (Cont'd)

Angles	Sines		Cosines		Tangents		Cotangents		Angles
	Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.	
36° 00′	.5878	9.7692	.8090	9.9080	.7265	9.8613	1.3764	0.1387	54° 00′
10	.5901	7710	.8073	9070	.7310	8639	1.3680	1361	50
20′	.5925	7727	.8056	9061	.7355	8666	1.3597	1334	40
30	.5948	7744	.8039	9052	.7400	8692	1.3514	1308	30
40	.5972	7761	.8021	9042	.7445	8718	1.3432	1282	20
50	.5995	7778	.8004	9033	.7490	8745	1.3351	1255	10
37° 00′	.6018	9.7795	.7986	9.9023	.7536	9.8771	1.3270	0.1229	53° 00′
10	.6041	7811	.7969	9014	.7581	8797	1.3190	1203	50
20	.6065	7828	.7951	9004	.7627	8824	1.3111	1176	40
30	.6088	7844	.7934	8995	.7673	8850	1.3032	1150	30
40	.6111	7861	.7916	8985	.7720	8876	1.2954	1124	20
50	.6134	7877	.7898	8975	.7766	8902	1.2876	1098	10
38° 00′	.6157	9.7893	.7880	9.8965	.7813	9.8928	1.2799	0.1072	52° 00′
10	.6180	7910	.7862	8955	.7860	8954	1.2723	1046	50
20	.6202	7926	.7844	8945	.7907	8980	1.2647	1020	40
30	.6225	7941	.7826	8935	.7954	9006	1.2572	0994	30
40	.6248	7957	.7808	8925	.8002	9032	1.2497	0968	20
50	.6271	7973	.7790	8915	.8050	9058	1.2423	0942	10
39° 00′	.6293	9.7989	.7771	9.8905	.8098	9.9084	1.2349	0.0916	51° 00′
10	.6316	8004	.7753	8895	.8146	9110	1.2276	0890	50
20	.6338	8020	.7735	8884	.8195	9135	1.2203	0865	40
30	.6361	8035	.7716	8874	.8243	9161	1.2131	0839	30
40	.6383	8050	.7698	8864	.8292	9187	1.2059	0813	20
50	.6406	8066	.7679	8853	.8342	9212	1.1988	0788	10
40° 00′	.6428	9.8081	.7660	9.8843	.8391	9.9238	1.1918	0.0762	50° 00′
10	.6450	8096	.7642	8832	.8441	9264	1.1847	0736	50
20	.6472	8111	.7623	8821	.8491	9289	1.1778	0711	40
30	.6494	8125	.7604	8810	.8541	9315	1.1708	0685	30
40	.6517	8140	.7585	8800	.8591	9341	1.1640	0659	20
50	.6539	8155	.7566	8789	.8642	9366	1.1571	0634	10
41° 00′	.6561	9.8169	.7547	9.8778	.8693	9.9392	1.1504	0.0608	49° 00′
10	.6583	8184	.7528	8767	.8744	9417	1.1436	0583	50
20	.6604	8198	.7509	8756	.8796	9443	1.1369	0577	40
30	.6626	8213	.7490	8745	.8847	9468	1.1303	0532	30
40	.6648	8227	.7470	8733	.8899	9494	1.1237	0506	20
50	.6670	8241	.7451	8722	.8952	9519	1.1171	0481	10
42° 00′	.6691	9.8255	.7431	9.8711	.9004	9.9544	1.1106	0.0456	48° 00′
10	.6713	8269	.7412	8699	.9057	9570	1.1041	0430	50
20	.6734	8283	.7392	8688	.9110	9595	1.0977	0405	40
30	.6756	8297	.7373	8676	.9163	9621	1.0913	0379	30
40	.6777	8311	.7353	8665	.9217	9646	1.0850	0354	20
50	.6799	8324	.7333	8653	.9271	9671	1.0786	0329	10
43° 00′	.6820	9.8338	.7314	9.8641	.9325	9.9697	1.0724	0.0303	47° 00′
10	.6841	8351	.7294	8629	.9380	9722	1.0661	0278	50
20	.6862	8365	.7274	8618	.9435	9747	1.0599	0253	40
30	.6884	8378	.7254	8606	.9490	9772	1.0538	0228	30
40	.6905	8391	.7234	8594	.9545	9798	1.0477	0202	20
50	.6926	8405	.7214	8582	.9601	9823	1.0416	0177	10
44° 00′	.6947	9.8418	.7193	9.8569	.9657	9.9848	1.0355	0.0152	46° 00′
10	.6967	8431	.7173	8557	.9713	9874	1.0295	0126	50
20	.6988	8444	.7153	8545	.9770	9899	1.0235	0101	40
30	.7009	8457	.7133	8532	.9827	9924	1.0176	0076	30
40	.7030	8469	.7112	8520	.9884	9949	1.0117	0051	20
50	.7050	8482	.7092	8507	.9942	9975	1.0058	0025	10
45° 00′	.7071	9.8495	.7071	9.8495	1.0000	0.0000	1.0000	0.0000	45° 00′
	Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.	
Angles	Cosines		Sines		Cotangents		Tangents		Angles

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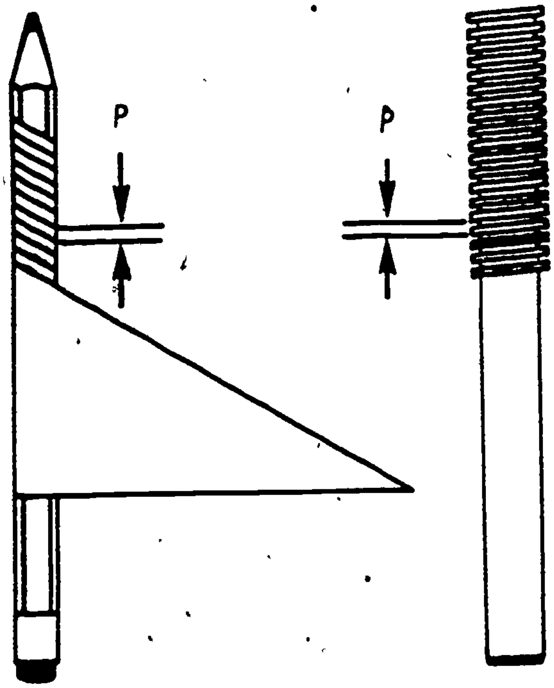


Figure 44. The screw is a variation of an inclined plane.

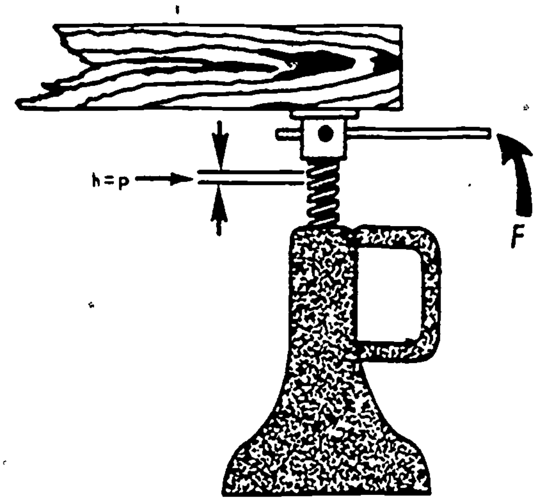
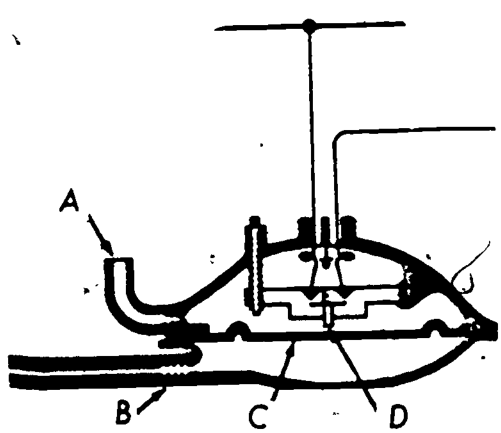


Figure 45. A jackscrew.



A. LOW-PRESSURE PORT
B. HIGH-PRESSURE PORT
C. DIAPHRAGM
D. MICROSWITCH

Figure 46. Pressure switch

Foldout 1

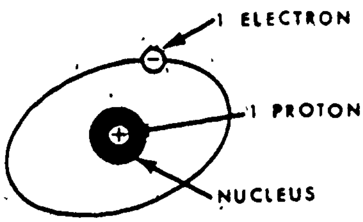


Figure 47.

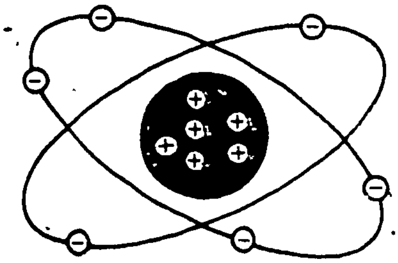


Figure 48

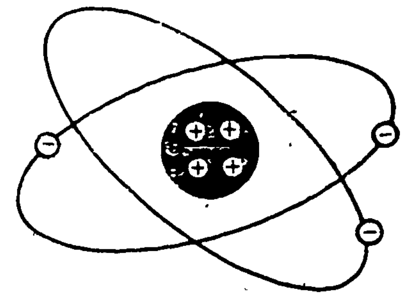


Figure 49

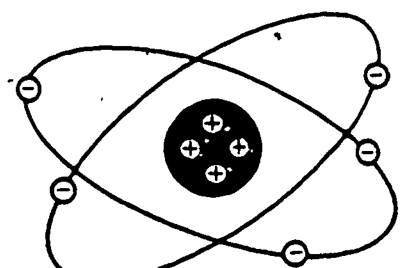


Figure 50.

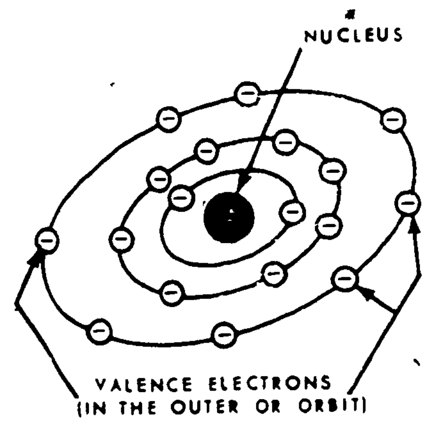


Figure 51

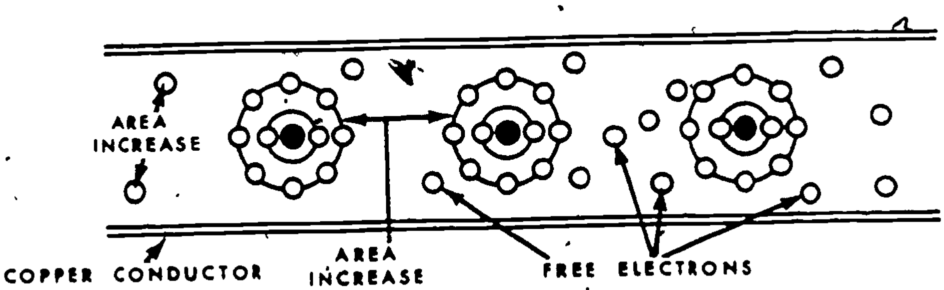


Figure 52.

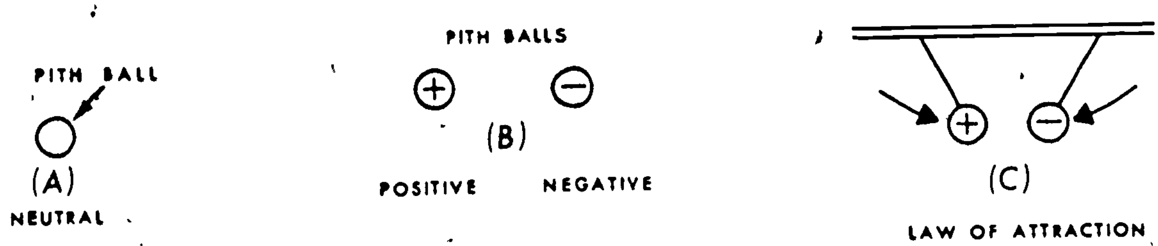


Figure 53.

Foldout 1 (Figures 44-5.

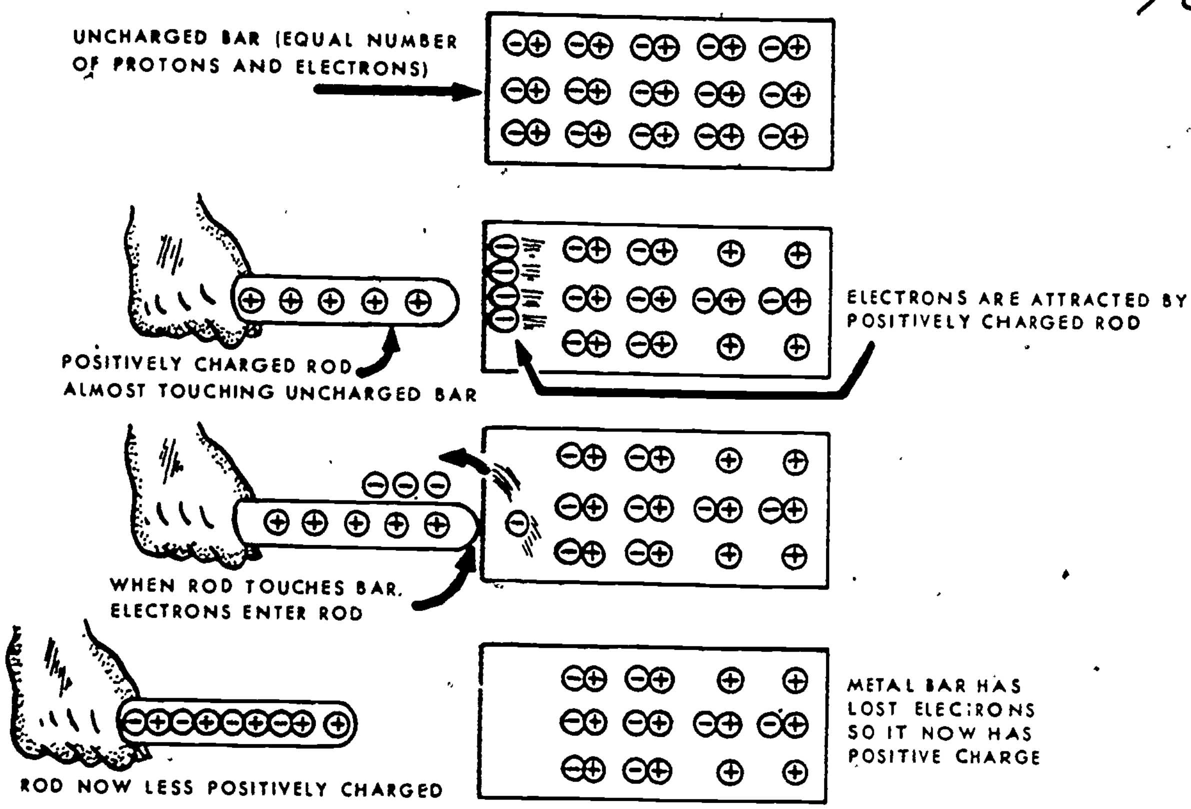


Figure 54

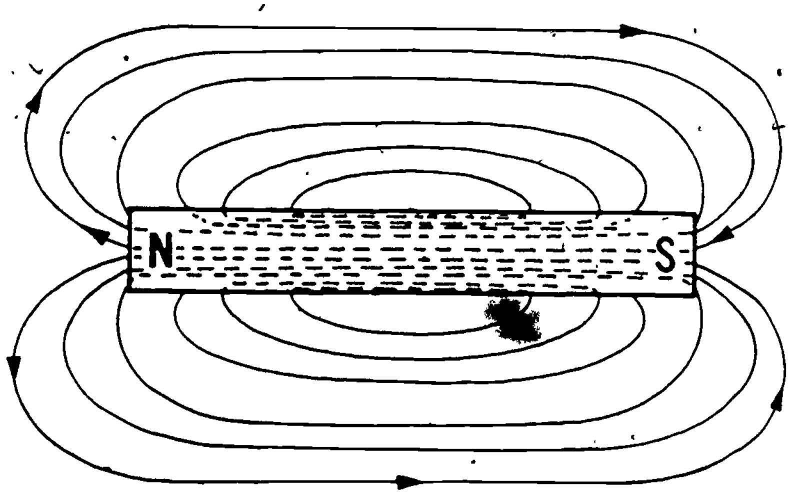


Figure 57 Flux pattern of bar magnet.

Foldout 2.

160

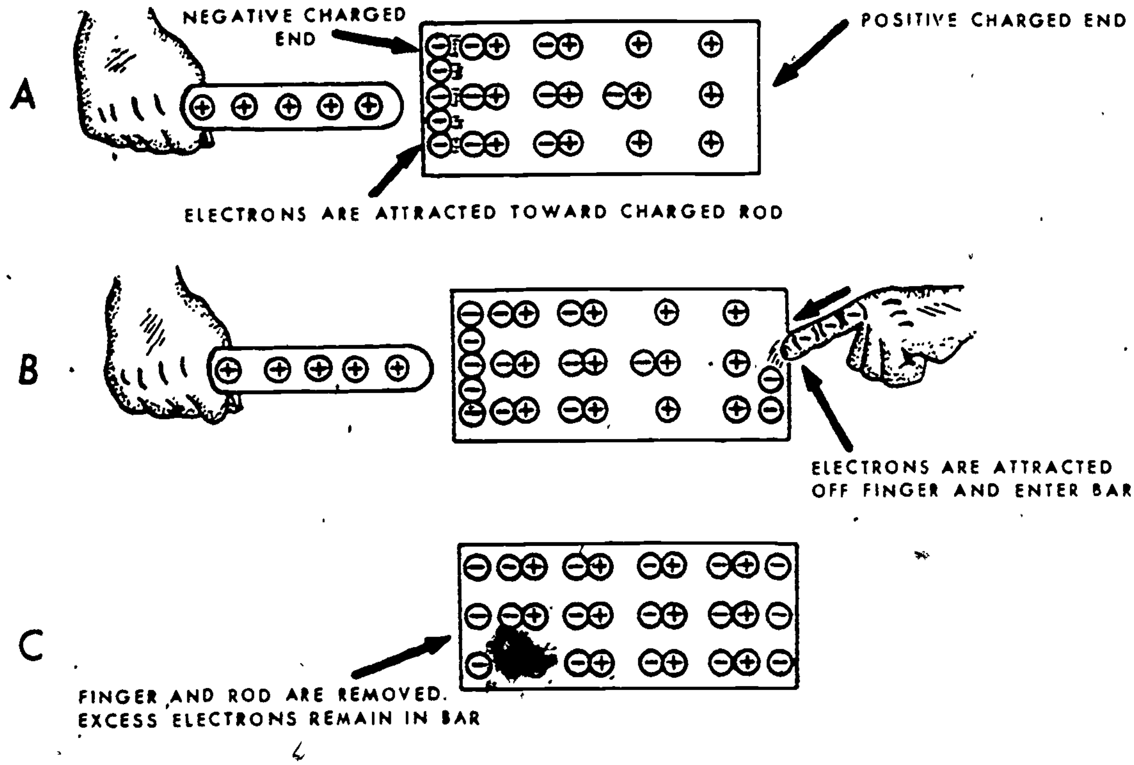


Figure 55

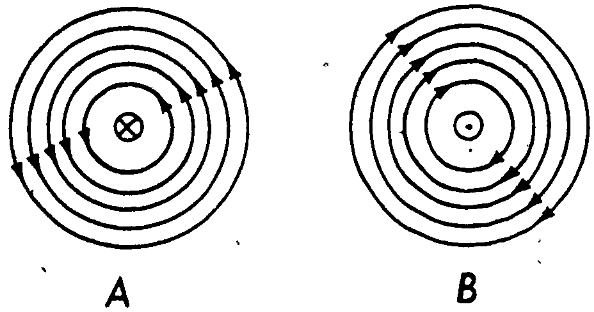


Figure 58 Magnetic fields about current-carrying conductors.

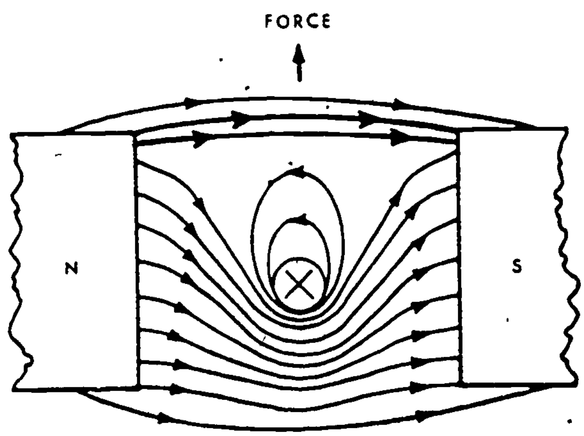


Figure 59 Composite magnetic field of magnets and conductors.

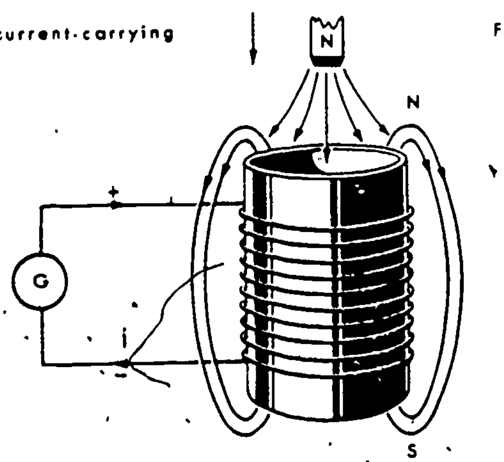


Figure 61 Inducing voltage in a solenoid.

Foldout 2.

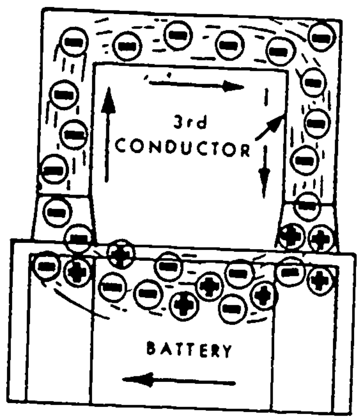
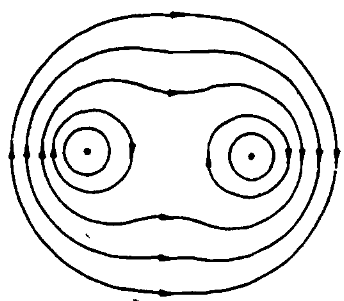


Figure 56



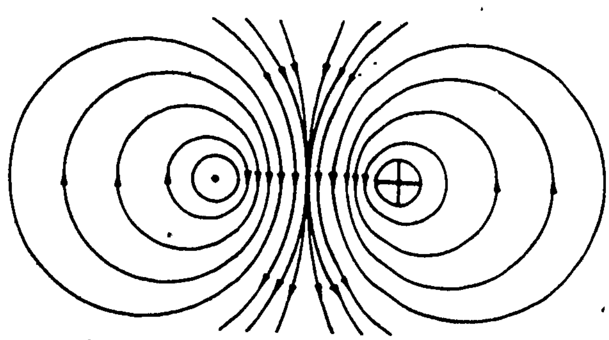


Figure 60 Field surrounding two adjacent conductors

Foldout 2 (Figures 54–61).

162

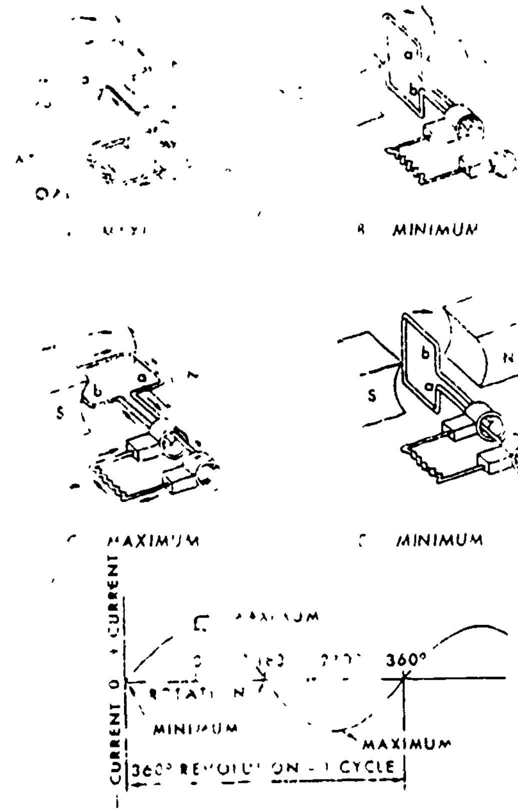


Figure 62. Simple ac generator

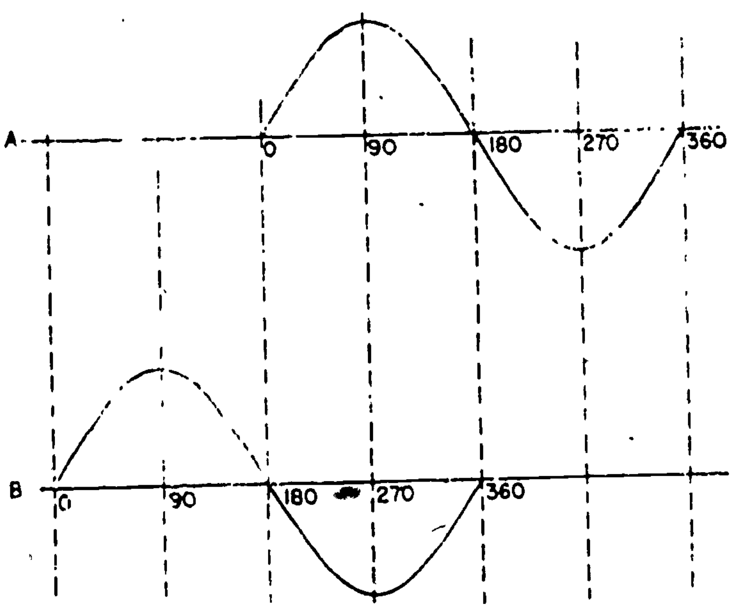


Figure 63. Phase relationships

Foldout 3.

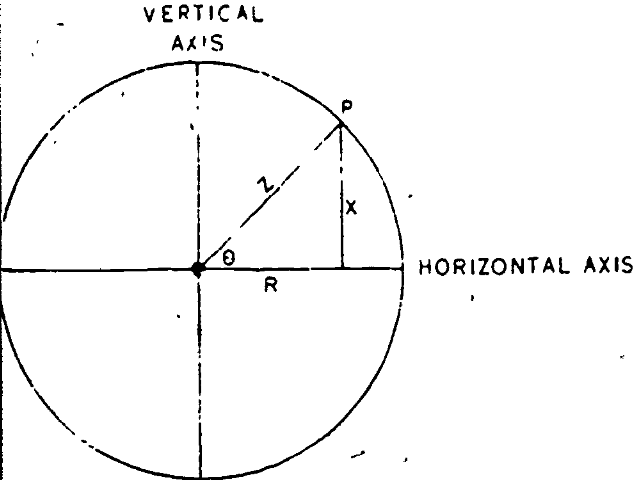


Figure 65 Finding trigonometric functions

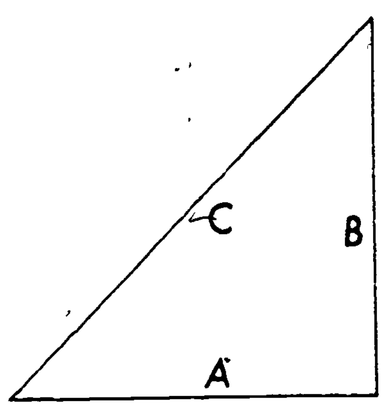


Figure 64 Right triangle

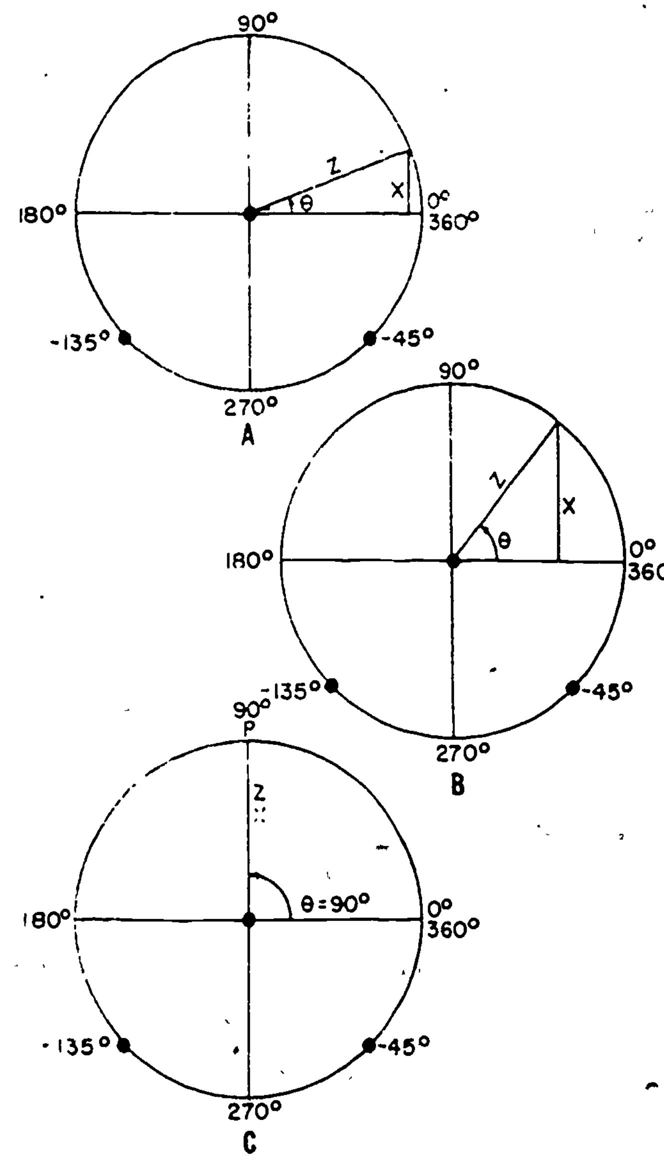


Figure 66 Effect of angle on vertical component

Foldout 3.

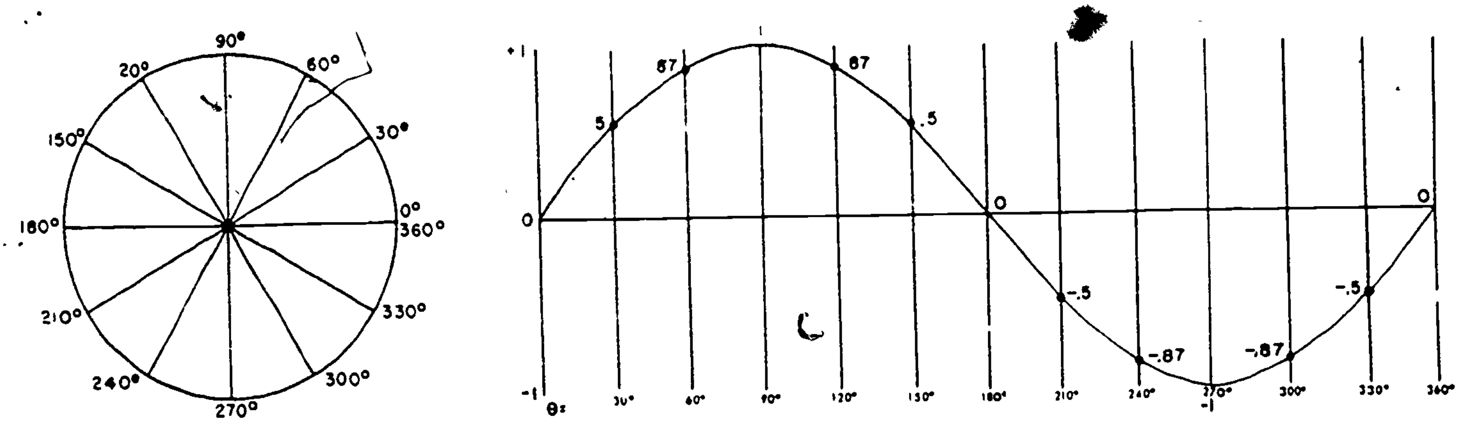


Figure 67 The sine wave curve

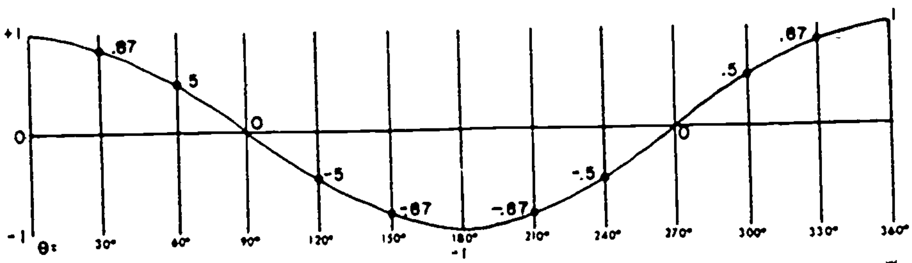


Figure 68 The cosine wave curve

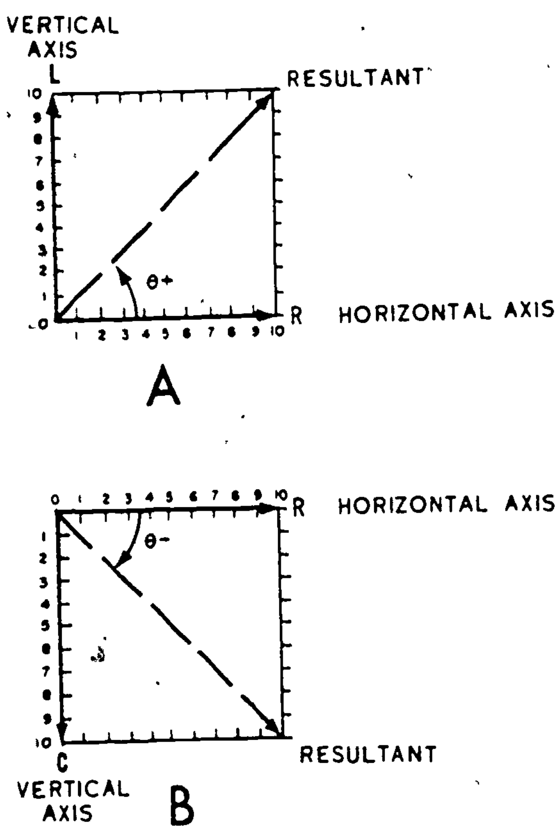


Figure 69 Two vectors representing quantities

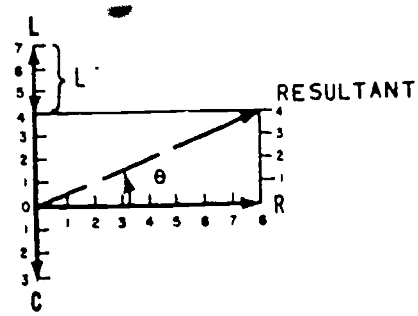


Figure 70 Three vectors representing quantities

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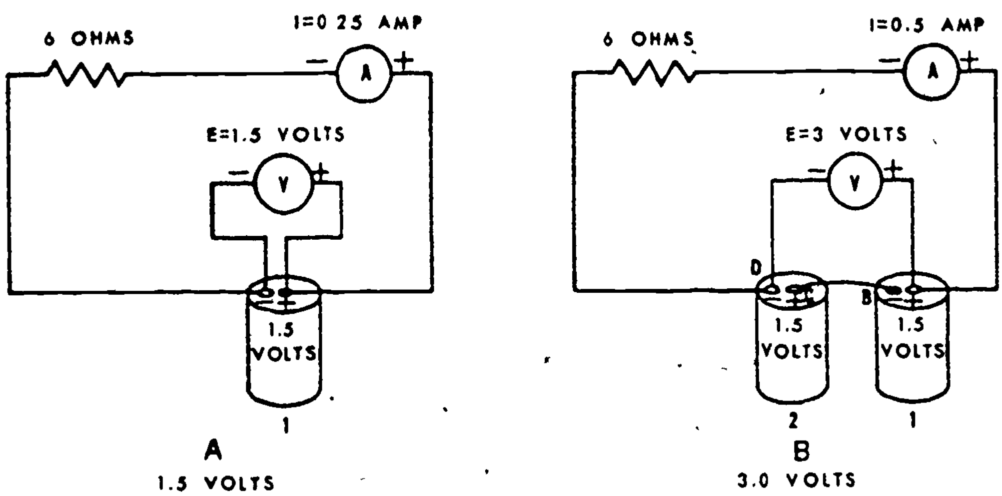


Figure 71. Circuit Used To Observe Change in I with a Change in E

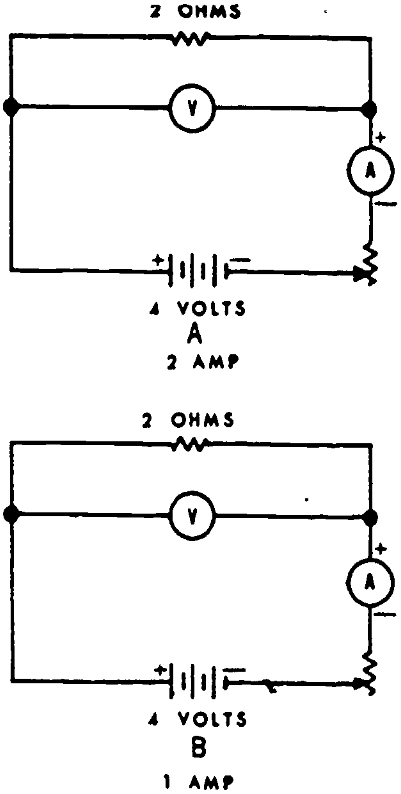


Figure 73. Circuit Used To Observe Change in E with a Change in I

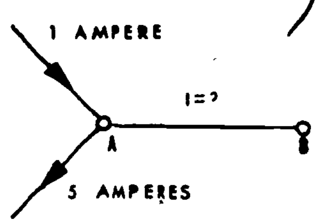


Figure 74. Example of Kirchhoff's First Law

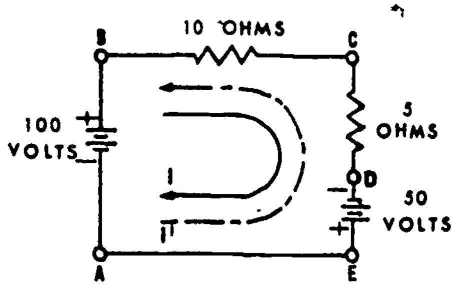


Figure 75. Example of Kirchhoff's Second Law

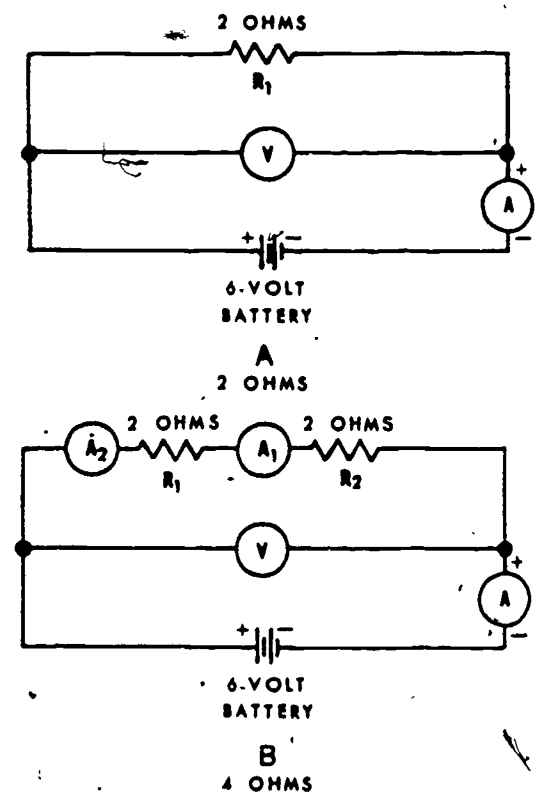


Figure 72. Circuit Used To Observe Change in I with a Change in R

Foldout 4 (Figures 71–75).

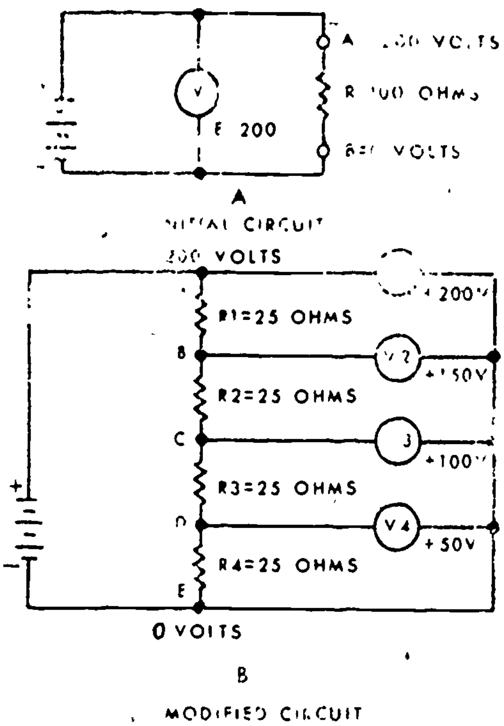


Figure 76 Rise or Fall of Potential

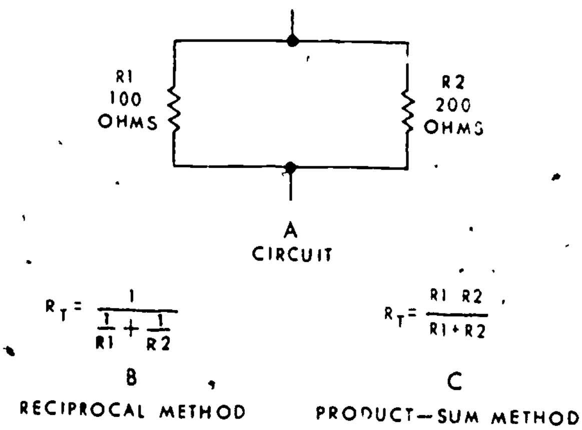


Figure 78 Methods of Calculating Equivalent Parallel Resistance

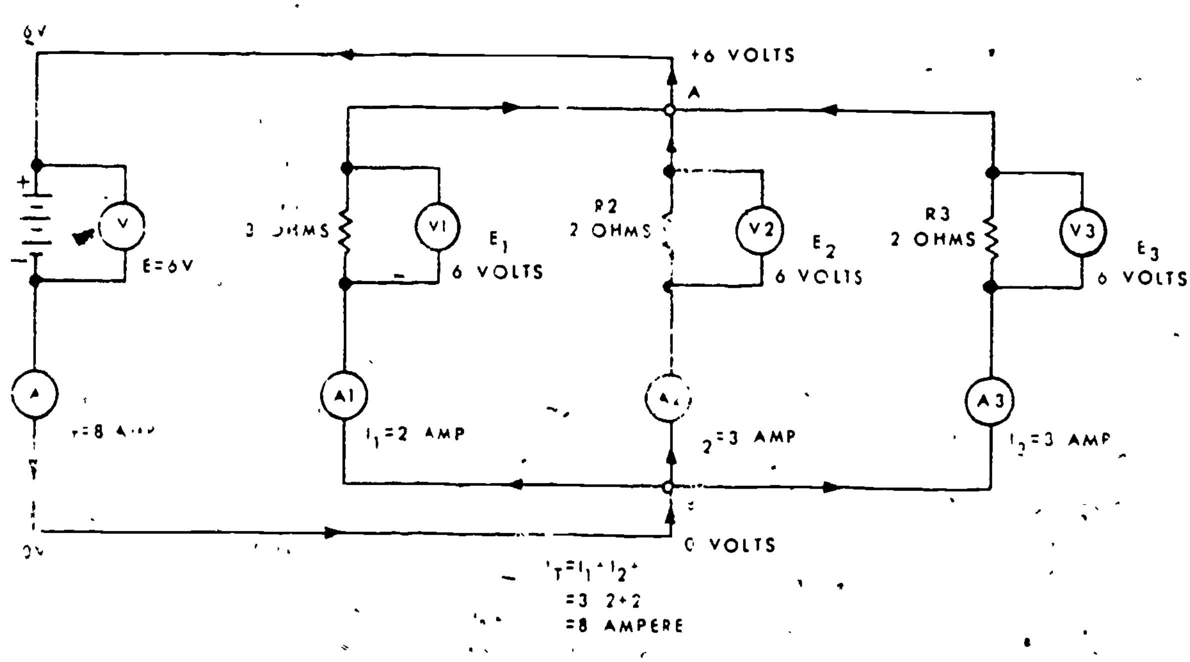
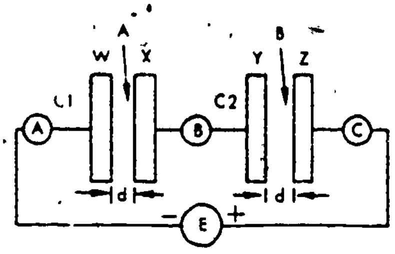


Figure 77 Voltage and Current Distribution in a Parallel Circuit

Foldout 5.



$C=\frac{1}{\frac{1}{C1}+\frac{1}{C2}}$

B

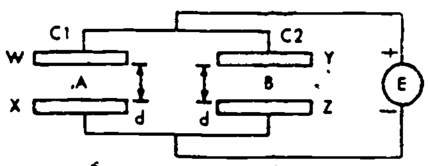
RECIPROCAL METHOD

$C=\frac{C1\ C2}{C1+C2}$

C

PRODUCT— SUM METHOD

Figure 79 Methods of Calculating Equivalent Series Capacitance



$C_T=C1+C2$

B

EQUATION

Figure 80 Parallel Capacitor Circuit

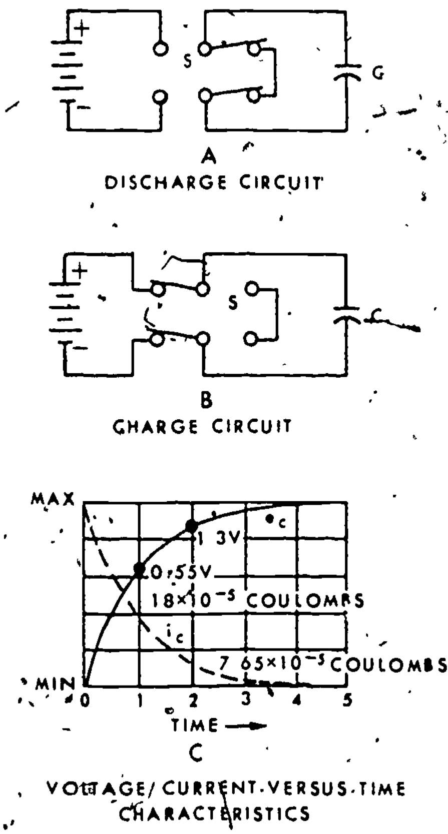


Figure 81 Capacitor Characteristics in a DC Circuit

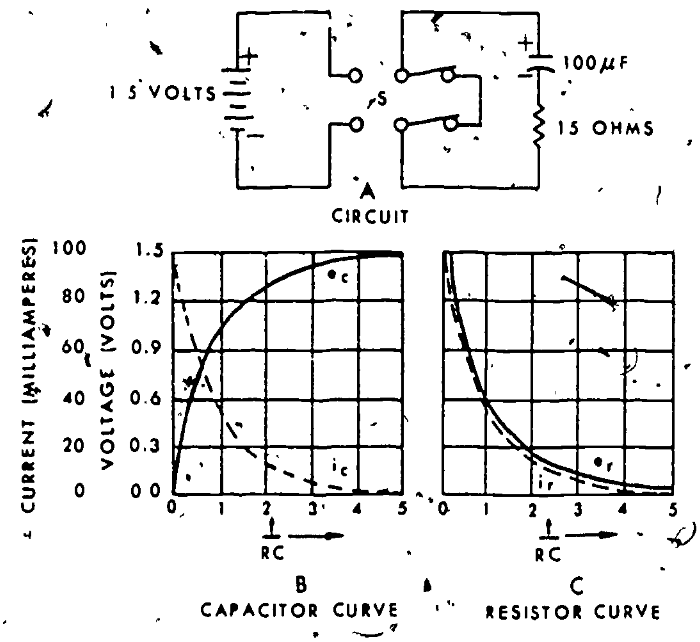


Figure 82 Series Resistance—Capacitance Circuit (Charging)

Foldout 5.

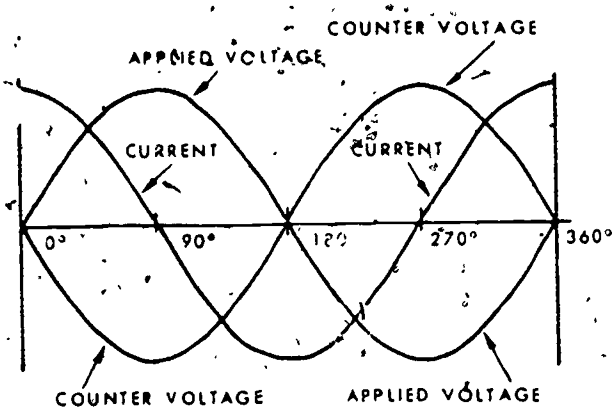


Figure 83 Relationship of Current to Applied and Counter Voltages

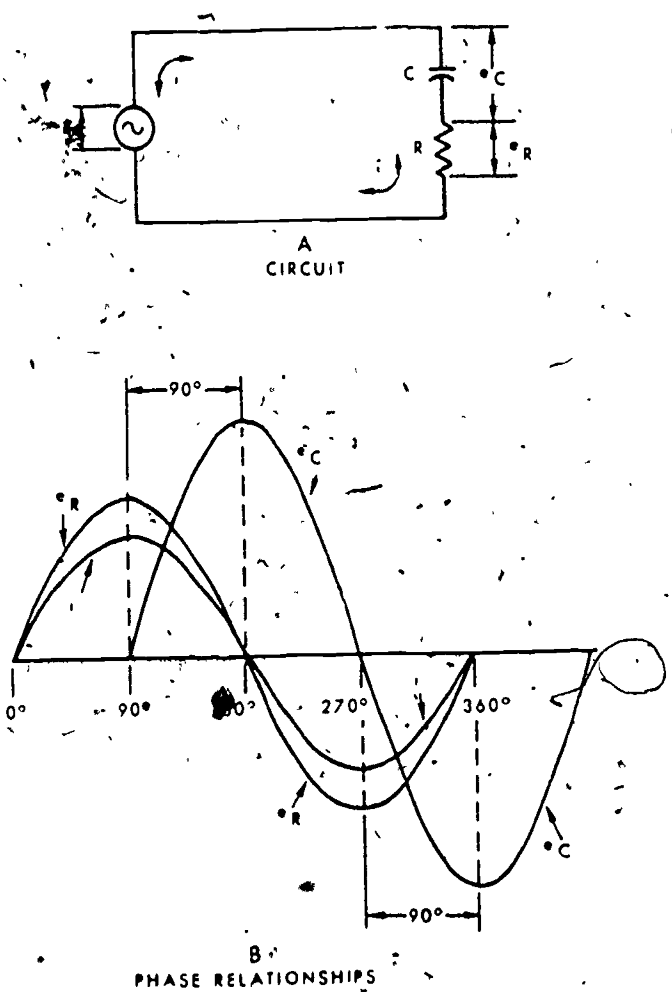


Figure 84 Phase Relationship in RC Circuits

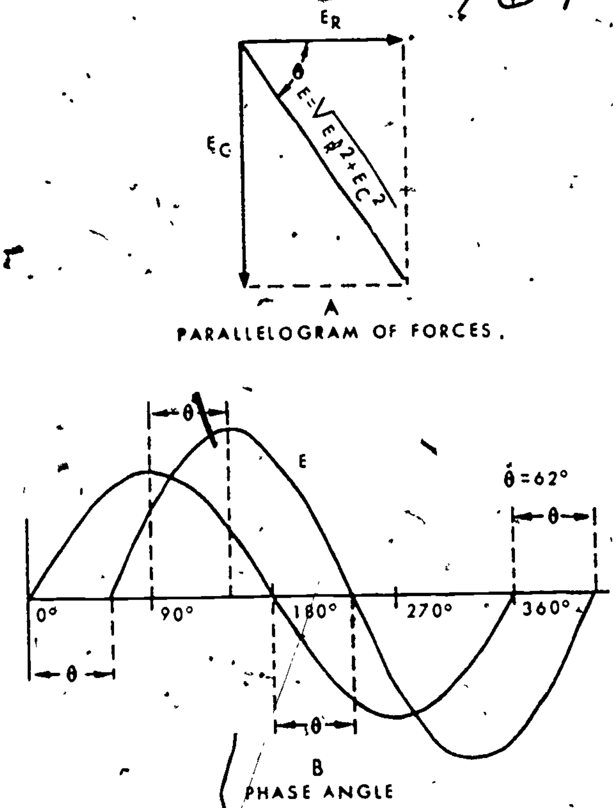


Figure 85 Vector Representation of Capacitive Phase Angle

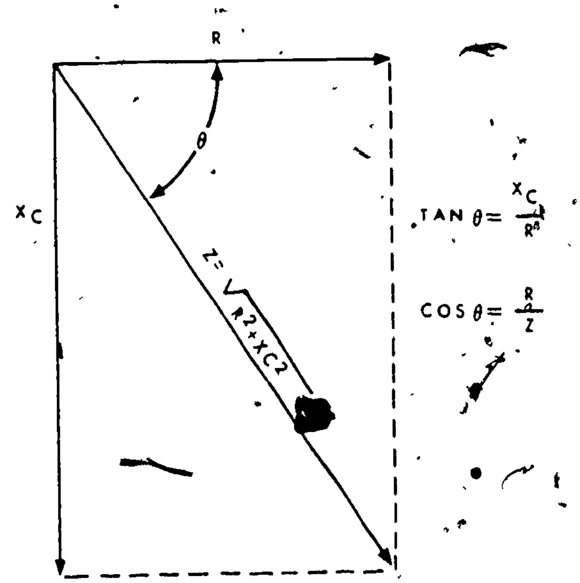


Figure 86 Impedance of an RC Circuit,

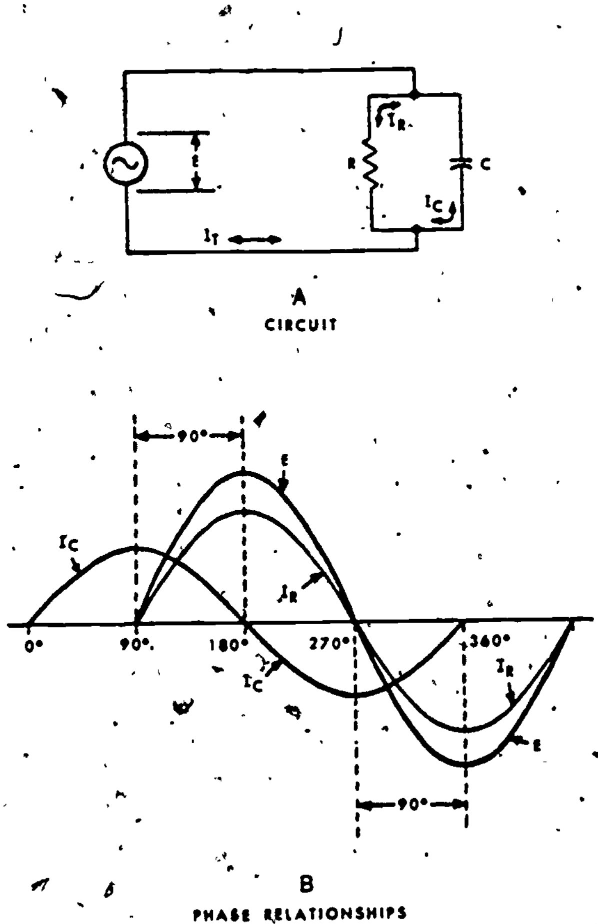


Figure 87. Voltage-Current Relationships in Parallel RC Circuit

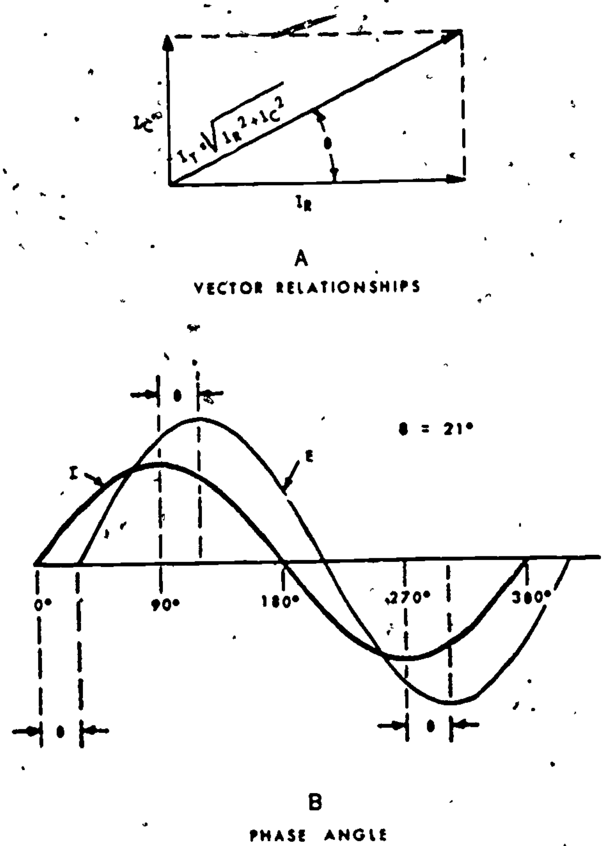


Figure 88. Current Vectors in Parallel RC Circuit

Foldout 6.

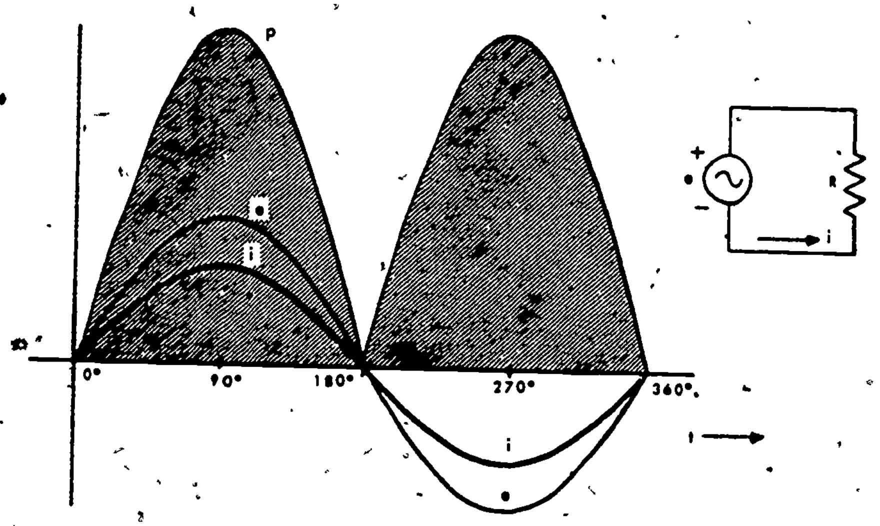


Figure 89 Power in a Pure Resistive Circuit

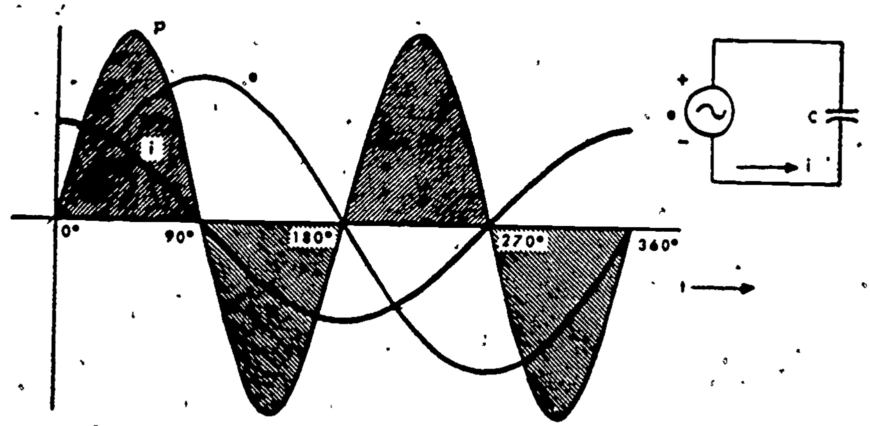


Figure 90. Power in a Pure Capacitive Circuit

Foldout 6 (Figures 87–90).

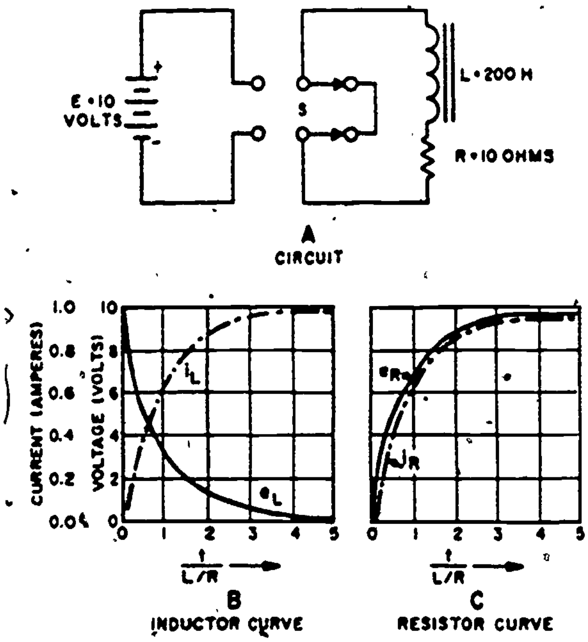


Figure 91. Series Inductance-Resistance Circuit (Growth Cycle)

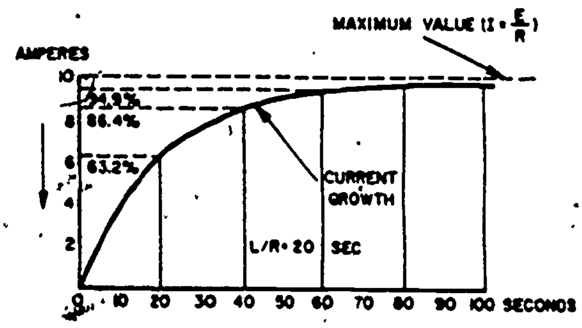


Figure 92. Inductor Current Growth (Percent)

Foldout 7.

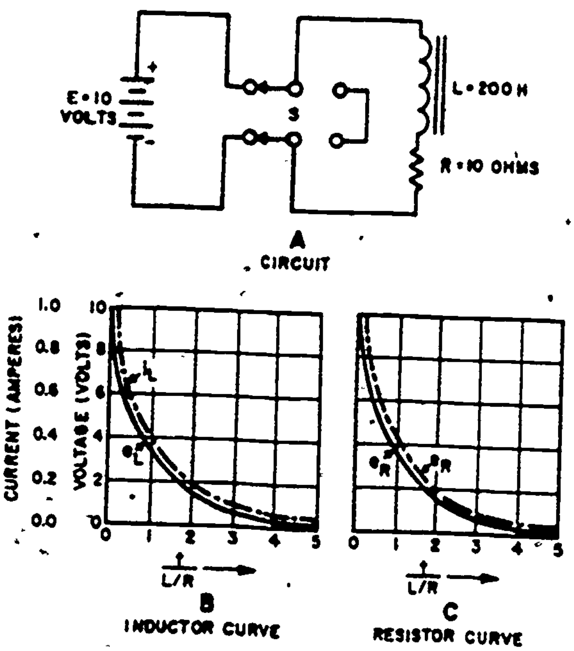


Figure 93 Series Inductance-Resistance Circuit (Decay Cycle)

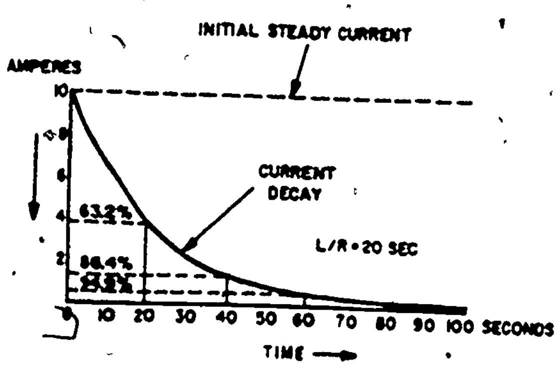


Figure 94 Inductor Current Decay (Percent)

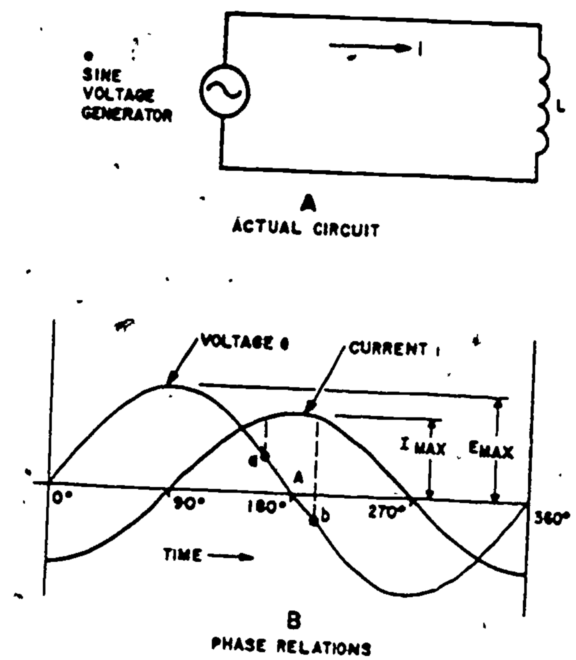


Figure 95 Phase Relationships in Inductive Circuits

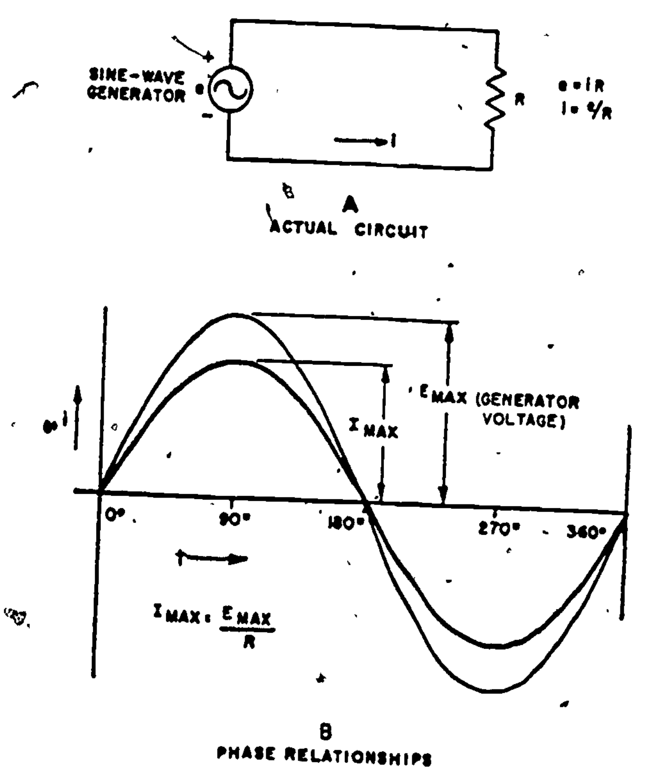
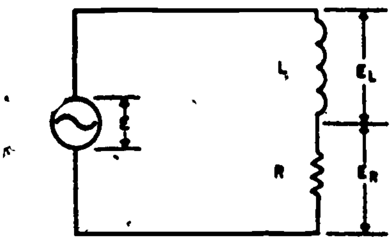
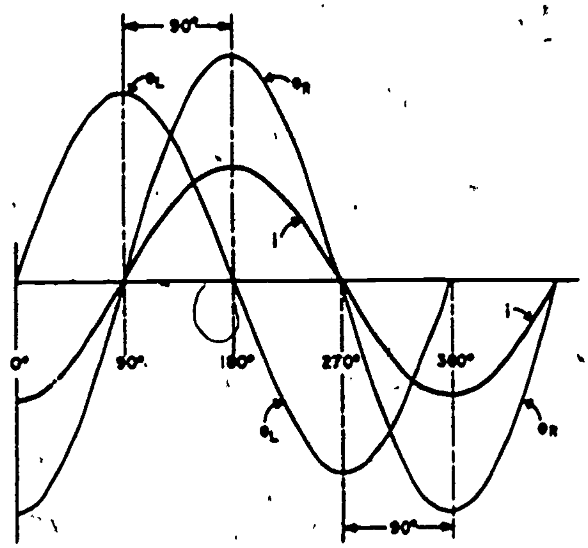


Figure 96. Phase Relationships in Resistive Circuits

Foldout 7.

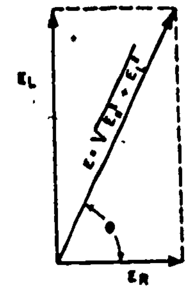


A
ACTUAL CIRCUIT

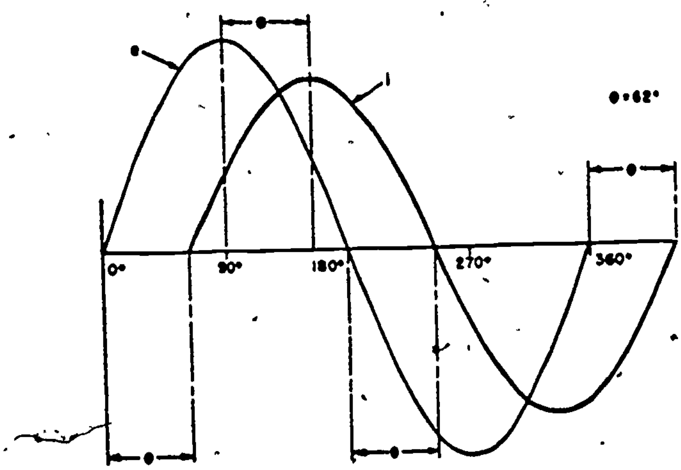


B
PHASE RELATIONS

Figure 97. Phase Relationships in Series LR Circuits



A
VECTOR DIAGRAM



B
PHASE RELATIONSHIPS

Figure 98. Vectorial Representation of Inductive Phase Relationships

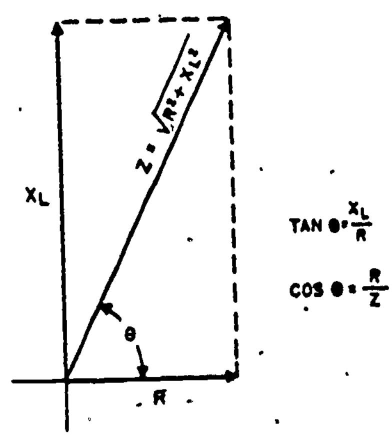
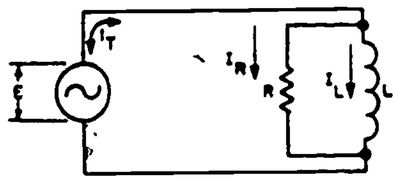
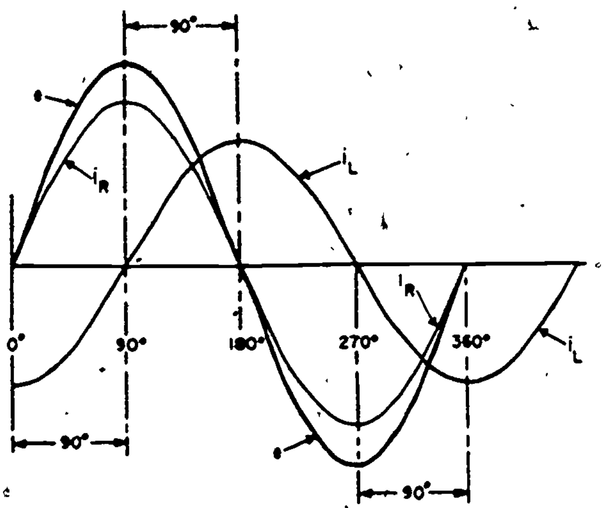


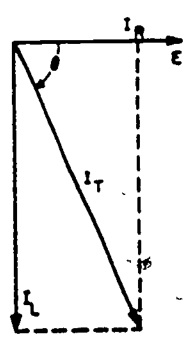
Figure 99. Vector Diagram of Series LR Circuit Impedance, Reactance, and Resistance



A
ACTUAL CIRCUIT

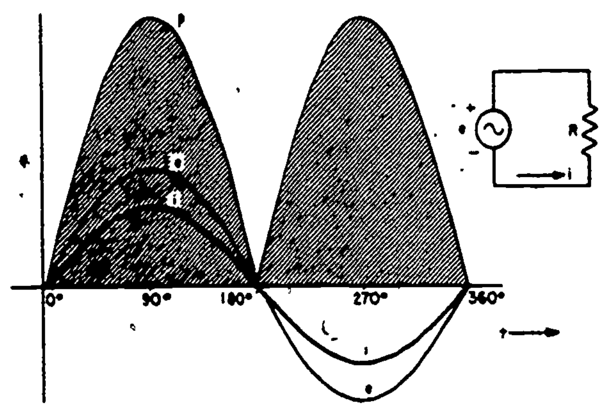


B
PHASE RELATIONSHIPS

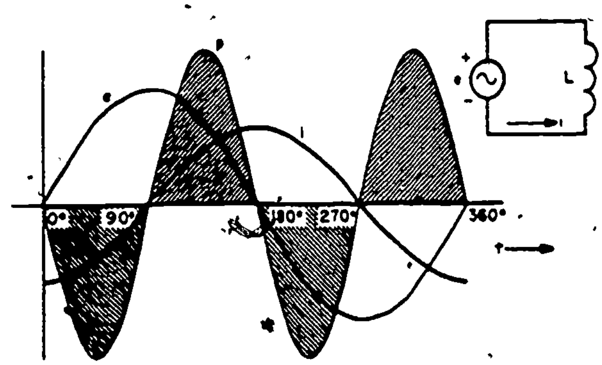


C
VECTOR DIAGRAM

Figure 100. Phase Relationships in Parallel LR Circuits



A
RESISTIVE CIRCUITS



B
INDUCTIVE CIRCUITS

Figure 101. Power in Inductive Circuits

Foldout 7 (Figures 91–101).

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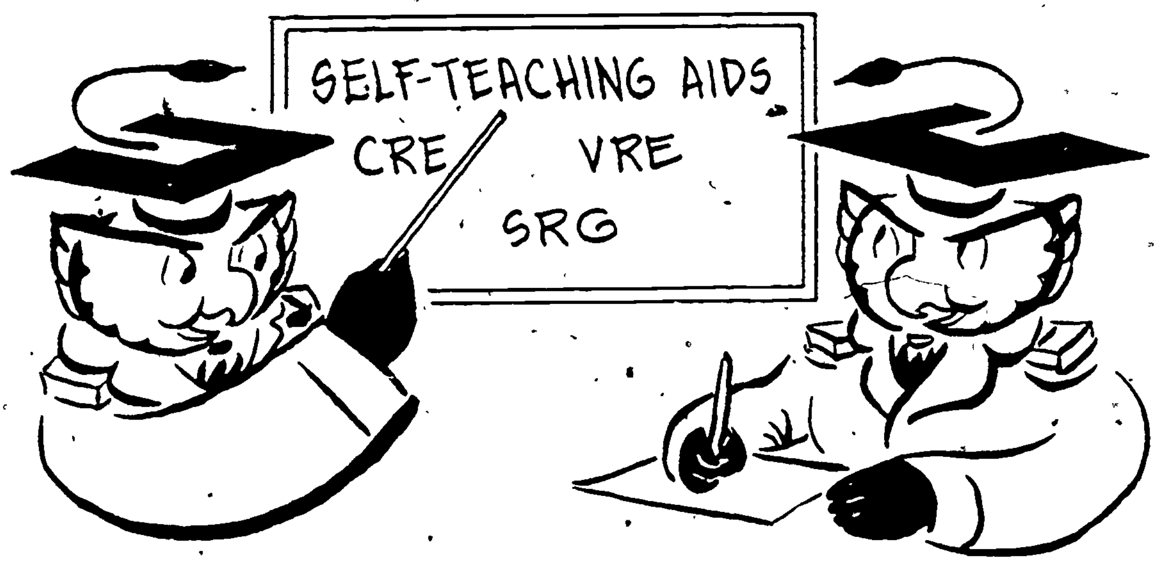
WORKBOOK

Aircraft Electrical Systems and Circuit Operation



This workbook places the materials you need *where* you need them while you are studying In it, you will find the Study Reference Guide, the Chapter Review Exercises and their answers, and the Volume Review Exercise. You can easily compare textual references with chapter exercise items without flipping pages back and forth in your text. You will not misplace any one of these essential study materials You will have a single reference pamphlet in the proper sequence for learning.

These devices in your workbook are autoinstructional aids. They take the place of the teacher who would be directing your progress if you were in a classroom. The workbook puts these self-teachers into one booklet. If you will follow the study plan given in "Your Key to Career Development," which is in your course packet, you will be leading yourself by easily learned steps to mastery of your text.

If you have any questions which you cannot answer by referring to "Your Key to Career Development" or your course material, use ECI Form 17, "Student Request for Assistance," identify yourself and your inquiry fully and send it to ECI.

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EXTENSION COURSE INSTITUTE

Air University

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1. *Use this Guide as a Study Aid.* It emphasizes all important study areas of this volume.

2. *Use the Guide as you complete the Volume Review Exercise and for Review after Feedback on the Results.* After each item number on your VRE is a three digit number in parenthesis. That number corresponds to the Guide Number in this Study Reference Guide which shows you where the answer to that VRE item can be found in the text. When answering the items in your VRE, refer to the areas in the text indicated by these Guide Numbers. The VRE results will be sent to you on a postcard which will list the *actual VRE items you missed.* Go to your VRE booklet and locate the Guide Number for each item missed. List these Guide Numbers. Then go back to your textbook and carefully review the areas covered by these Guide Numbers. Review the entire VRE again before you take the closed-book Course Examination.

3. *Use the Guide for Follow-up after you complete the Course Examination.* The CE results will be sent to you on a postcard, which will indicate "Satisfactory" or "Unsatisfactory" completion. The card will list *Guide Numbers* relating to the questions missed. Locate these numbers in the Guide and draw a line under the Guide Number, topic, and reference. Review these areas to insure your mastery of the course.

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100	Introduction to a Maintenance Organization; Field Maintenance Squadron, pages 1-5
101	Security, Supervision, and Training Responsibilities: Communications Security, pages 5-7
102	Security, Supervision, and Training Responsibilities: Airman Performance Reports, pages 7-9
103	Security, Supervision, and Training Responsibilities: Training, pages 9-13
104	Introduction to Flight Line Safety for the Electrician; Flight Line Safety, pages 14-18
105	Good Housekeeping and Fire Prevention, pages 18-20
106	Introduction to Major Aircraft Systems and Electrical Maintenance and Inspection; Aircraft Familiarization, pages 21-23
107	Aerodynamics and Flight Control, pages 23-28
108	Major Aircraft Systems, pages 28-33
109	Servicing Materials for Aircraft Systems, pages 33-35
110	Electrical Hardware and Handtools: Electrical Hardware–Safety Devices; Circuit-Controlling Devices; Circuit-Protection Devices, pages 35-39
111	Electrical Hardware and Handtools: Electrical Hardware–Terminals and Splices; Electrical Connections, pages 39-42
112	Electrical Hardware and Handtools: Electrical Hardware–Electrical Wires; Compact Wire Bundles; Terminal Blocks; Bonding and Grounding, pages 42-48
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MODIFICATIONS

Chapter 1, pages 3-6 of this publication has (have) been deleted in adapting this material for inclusion in the "Trial Implementation of a Model System to Provide Military Curriculum Materials for Use in Vocational and Technical Education." Deleted material involves extensive use of military forms, procedures, systems, etc. and was not considered appropriate for use in vocational and technical education.

CHAPTER 2

Objective: To demonstrate a general knowledge of the safety measures required while performing his daily work.

1. Describe people who are referred to as "accident prone" and "safety conscious." (Intro.-2, 3)

2. What area should be avoided when working around a reciprocating engine? (3-4)

3. Name the danger areas around a jet engine. (3-5, 6)

4. What protective equipment should be worn around a jet engine? (3-7)

5. Where can you find the safe way of approaching a helicopter? (3-10)

6. What attitude should one have when entering a cockpit? (3-13)

7 Why do pneudraulically operated systems present such hazards to safety? (3-16)

8. An aircraft on jacks presents may potential hazards. There should be an observer for this operation Where is the best position for this man? (3-18)

9. What part of the body is most susceptible to radar beams? (3-19)

10 Who is responsible for your knowledge concerning radioactive material? (3-21)

11 What is good housekeeping? (4-1)

12 What two things cause many fires? (4-9)

13 Safety is whose responsibility? (4-12)

CHAPTER 3

Objective. To acquire a job knowledge of aerodynamic principles, major aircraft control systems, and the installation, repair, and inspection of aircraft electrical wiring and related hardware.

1. What type aircraft is used to engage the enemy on the ground and in the air? (5-4)

2 What is one of the most prominent distinguishing features of an aircraft? (5-8)

3 What are the three wing designs mentioned in this text? (5-9-11)

4 What is the purpose of aircraft designation? (5-13)

5 What is the reference line often used in discussing an airfoil? (6-3)

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6. What are the four aerodynamic forces that act upon an airfoil? (6-4)

7. What is meant by the term "relative wind" when discussing principles of flight? (6-8)

8. What is the angle of attack? (6-9)

9. What is a flight axis? (6-11)

10. Name the flight axes of an aircraft. (6-12)

11. Name the movement around each flight axis. (6-13)

12. What causes the aircraft to move around its flight axis? (6-16)

13. What is the purpose of the secondary flight control surfaces? (6-21)

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14. When the turbine-driven hydraulic pump fails, what type of power is used for the alternate source? (7-2)

15. What controls the landing gears and how are they actuated? (7-6)

16. What system prevents the wheels from locking during landing? (7-7)

17. By what means are electrical requirements met on an aircraft? (7-8)

18. What is the function of the CSD? (7-9)

19. Name four functions that an AC voltage regulator may perform. (7-10)

20. What is the function of the AC generator control panel? (7-11)

21. If a section of aircraft tubing is color coded with red marking tape can you connect electrical wiring to the tubing? Why? (8-4)

22. How are hydraulic fluids generally classified? (8-5)

23. Why is it necessary to pay particular attention to lubricating instructions? (8-14)

24. What are the most commonly used safety devices? (9-3)

25. What is the common designation of an electrical switch? (9-8)

26. What type of switch can be used to perform the function of a number of switches? (9-11)

27. What are mechanically operated switches used for? (9-12)

28. What type switch is used in fire-warning circuits? (9-14)

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29. What are electrically operated switches called? (9-18)

30. What two devices are used to control the intensity of lights? (9-22)

31. What is the simplest overcurrent protection device? (9-27)

32. How may one know that the bakelite fuse is good or bad? (9-31)

33. Where are current limiters generally placed in a parallel bus feeder system? (9-33)

34 What advantage does the circuit breaker have over the fuse and current limiters? (9-35)

35 What type of breaker is used in circuits which would constitute an in-flight emergency if they were not energized? (9-40)

188

36. What special case authorizes a soldered terminal or splice? (9-42)

37. What advantage do crimp-on terminals and splices have on soldered connections? (9-44)

38. What two assemblies make up an electrical connector? (9-50)

39. What is the purpose of installing a short length of wire in all unused pins of an electrical connector? (9-54)

40. What physical characteristics of copper wire account for its wide usage? (9-55)

41. Where is aluminum wire generally used? (9-56)

42. How is wire size designated? (9-59)

43. What is the proper distances when marking wire? (9-64)

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44. What precaution is taken when routing wires through hot areas? (9-70)

45. How should wire bundles be installed across hinges? (9-74)

46. Where is wire lacing authorized? (9-78)

47. What advantage do compact wire bundles have over conventional wire bundles? (9-79)

48. What is the purpose of terminal block? (9-84)

49. What is meant by bonding? (9-89)

50. How are the letter number combinations processed into the instalation of the wires? (9-93)

51. What is one secret to good soldering, according to the text? (9-94)

52. How are good soldering techniques developed? (9-97)

53. What tool has taken the place of the soldering iron in many cases? (9-98)

54. What two tools are commonly used to remove insulation from wires? (9-102)

55. What is the purpose of inspecting the electrical system? (10-2)

56. What technical order covers electrical system inspection procedures? (10-4)

57. How should wiring be routed in regard to combustible or oxygen lines? (10-11)

58. What is the maximum interval for support clamps when installing wire bundles? (10-13)

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Objective To acquire a working knowledge of the operating principles and application of measuring devices required to performance test aircraft electrical systems and components.

1 After each electrical quantity shown below, indicate what instrument is used to measure its effect.

a. Electron movement.
b Difference in potential.
c. Opposition to current flow in a DC circuit
(Intro -2)

2 A thorough understanding of the operation and limitations of measuring devices is essential to what three phases of your job as an electrician? (Intro.-5)

3 What type of meter movement is found in most electrical test instruments you will use on the job? (11-2)

4. What provides the turning force of a moving-coil meter movement? (11-3)

5 To produce a useful interaction in a D'Arsonval meter movement, what condition must exist? (11-3)

6 Why is the D'Arsonval meter movement used in a multimeter? (11-4)

7. What determines the sensitivity of a meter? (11-5)

8. What process is used to overcome overshooting and oscillation of the meter pointer? (11-6)

9. Why must the total resistance of an ammeter be kept low? (11-7)

10. How are ammeters connected in a circuit? (11-9)

11. What is the correct procedure for checking an unknown current with a multirange ammeter? (11-10)

12. How are voltmeters connected in a circuit? (11-12, 18)

13. What is the effect of using a low-resistance voltmeter across a high-resistance circuit? (11-21)

14. How does the electrodynamometer type meter differ from the D'Arsonval meter? (11-22)

15. What controls overshooting and pointer oscillation in the electrodynamometer type meter movement? (11-25)

16. What controls the ohmeter pointer deflection? (11-29)

17. Why must each ohmeter range (R × 1, R × 10, etc.) be zero-adjusted? (11-32)

18. When resistance measurements are made in electrical circuits, what is the primary precaution to be observed? (11-35)

19. In checking electrolytic capacitors with the ohmmeter, why must polarity be observed? (11-41)

20. What is the primary function of a megger? (11-43)

21. What megger voltage is used in one military application? (11-44)

22. What does a typical multimeter contain? (11-51)

23. When measuring an AC voltage with a DC moving-coil meter, what must be in the meter circuit? (11-54)

24. How is meter sensitivity affected when a half-wave meter circuit is replaced with a full-wave circuit? (11-55)

25. What value of the sine wave of voltage or current are AC meters calibrated to read? (11-56)

26. What is used to increase the input resistance of a basic VTVM? (11-62)

27. What measuring device was designed to measure peak-to-peak values? (11-66)

28. What meter measures electrical power in the aircraft? (11-69)

29. What type reading will be obtained from a circuit with a low-power factor? (11-71)

30. What type meter movement is used in the watt-varmeter? (11-73)

31. How can the power factor of a circuit be determined? (11-75)

32. What are the three types of frequency meters mentioned in the text? (11-79-81)

33. Why must the intensity control be turned down on the oscilloscope after it has been turned on? (12-3)

34. What devices are used to adjust the electron beam vertically and horizontally on the oscilloscope? (12-4)

35. How is the length of the sweep changed? (12-7)

36. What must be known before using the oscilloscope to determine an unknown AC frequency? (12-11)

37. What are you looking for, in general, when examining a waveform in a class A amplifier circuit? (12-17)

38. What are the two general classifications of tube testers? (12-19)

39. Which type tube tester provides the most accurate means of testing? Why? (12-19)

40. What is used to compensate for differences in the line voltage on the transconductance tube tester covered in this text? (12-21)

41. What is connected in series with the primary transformer to prevent equipment damage? (12-24)

42. When a tube is under test, what indication reveals a shorted element? (12-25)

43. What is the purpose of tapping a tube during a noise test? (12-26)

44. When a tube is subjected to a gas test, what is an indication of excessive amount of gas in the tube? (12-27)

45. For what is the Wheatstone bridge generally used? (12-30)

CHAPTER 5

Objectives: To be able to relate the principles of simple machines, effects of pressure and temperature, and electron physics; and to state the general facts of the properties of metals and atomic structure of matter.

1. What is a machine? (13-2)

2. What does mechanical advantage of a machine measure? (13-4)

3. Name three examples of simple machines. (13-17)

4. How is pressure defined? (13-21)

5. How does a rise in temperature affect the resistance of the sensing element in a continuous cable fire-warning system? (13-30)

6. List three major particles in an atom. (13-35)

7. What would be the best description of a positive ion? (13-42)

8. What are the major electrical categories of materials in relationship to their ability to allow electric current to flow? (13-48)

9. Define a good electrical conductor. (13-49)

10. When is a material considered an insulator? (13-54)

11. How does an increase in temperature affect the resistance of semiconductor material? (13-58)

12. Name the three types of electrical charges. (13-61)

13. What effect will like electrical charges have on each other? (13-62)

14. What are three methods of producing a static electrical charge? (13-67-69)

15. Define current flow. (13-73)

16. What is voltage? (13-78)

17. What are the ends of a permanent magnet called? (14-2, 3)

18. How can the strength of the magnetic field around a conductor carrying a constant amount of current be increased? (14-13)

19. What is induction? (14-16)

20. In what direction would a current-carrying conduction move in a uniform magnetic field? (14-17)

21. How is the resultant magnetic field around two conductors affected when current in the conductors is in opposite directions. (14-20)

22. Name the factors that affect the magnitude of an EMF produced in a generator. (14-24)

23. What is a cycle of AC? (14-36, 37)

24. Define frequency in terms of cycles. (14-38)

25. What determines the frequency of an alternator? (14-40)

26. What is rms? (14-44-48)

27. What equation is used to find the hypotenuse of a right triangle? (15-8)

28. When plotting a sine wave curve, the maximum value or values attained is at what angle or angles? (15-19)

29. What is the angle whose cosine is .9397? (15-27)

CHAPTER 6

Objectives. To be able to use Ohm's law and Kirchhoff's laws to state the mathematical relationships of voltage, current, and resistance in series, parallel, and compound DC circuits, and to be able to state the basic properties of inductors and capacitors and analyze RC, RL, and RCC series and parallel circuits. Also, to be able to compute inductive and capacitance reactance, impedance, voltage, current, and power.

1. Define Ohm's law. (16-5)

2. What is the mathematical relationship between voltage, current, and resistance as stated by Ohm's law? (16-5)

3. How will an increase in circuit resistance affect circuit current? (16-10)

4. Define Kirchhoff's current law. (16-15, 16)

5. Define Kirchhoff's voltage law. (16-15, 17)

6. What is a series circuit? (16-21)

7. How is the total resistance in a series curcuit computed? (16-23)

8. What is the initial requirement before a voltage can be measured in a circuit? (16-26, 27)

9. How is the total battery voltage expended in a series circuit? (16-29)

10. Define power in a series resistive circuit. (16-30)

11. How is the voltage applied to each path in a parallel circuit related? (16-32)

12. How is total current computed in a parallel circuit? (16-38)

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13. What is the relationship between the total resistance and the resistance in each part of a parallel circuit? (16-39)

14. What is the formula for computing total resistance in a parallel circuit? (16-43, 44)

15. How are series-parallel circuits analyzed? (16-51)

16. Define a capacitor. (17-2)

17. What is the unit of capacitance? (17-4)

18. How does the distance between the plates of a capacitor affect its capacitance? (17-6)

19. How can you compute total capacitance in a series capacitance circuit? (17-6)

20. What limits the charging current at the instant a voltage is applied to a capacitor in an RC circuit? (17-14)

21. Define RC time constant. (17-17)

22. What is the phase relationship between capacitor voltage and capacitor current in a series RC circuit? (17-20)

23. What is the reference point for calculation of circuit constants in a series RC circuit? (17-21)

24. How can the relationship between applied voltage, voltage drops, and phase angle be determined in any series RC circuit? (17-22)

25. How can the phase angle be computed in a series RC circuit? (17-25)

26. What is the equation for capacitive reactance? (17-27)

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27. How is impedance computed in a series RC circuit? (17-28, 29)

28. How is total current computed in a parallel RC circuit? (17-33)

29. What is the best method of computing total impedance in a parallel RC circuit? (17-33)

30. What is reactive power? (17-38)

31. What is true power? (17-39)

32. Define power factor. (17-40)

33. Define inductance. (17-45)

34. What is the unit of measurement of inductance? (17-46)

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35. How can total inductance in a parallel circuit be computed? (17-49)

36. What is the expression for LR time constant? (17-56)

37. What is the line of reference for both inductance and resistance in a series LR circuit? (17-61)

38. What method can be used to compute total voltage in a series LR circuit? (17-62)

39. What is the inductive reactance equation? (17-66)

40. How can you compute impedance in a series LR circuit? (17-67)

41. What is normally the reference vector in parallel LR circuits? (17-72)

42. How are reactances treated in LCR circuits? (17-79)

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43. How is impedance found in LCR circuits? (17-79)

44. What is the condition for resonance? (17-81)

CHAPTER 7

Objectives: To be able to relate general operating principles of magnetic devices and their application to transformers and magnetic amplifier voltage regulators. Also, to be able to state the basic operation and application of semiconductor devices.

1. Explain hysteresis. (18-11)

2. Define saturation. (18-16)

3. What happens to the output of a magnetic amplifier when the core becomes completely saturated? (18-21, Part A, Fig. 114)

4. What determines the relationship between the input and output coils in a single magnetic amplifier? (8-24)

5. Why is a voltage reference necessary in a complete magnetic amplifier circuit? (18-27)

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6. What is the purpose of a feedback circuit? (18-30)

7. What is a transformer? (18-34)

8. Explain how energy is coupled from a primary to a secondary circuit of a transformer? (18-40)

9. How are transformers constructed to reduce losses? (18-47-49)

10. How many windings are there in an autotransformer? (18-52)

11. What is meant by the term "acceptor impurities"? (19-4)

12. What is meant by the term "donor impurities"? (19-5)

13. What happens when reverse bias is applied to a PN junction? (19-7)

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14. Why is it important that bias voltage not be allowed to become excessive? (19-7)

15. What is "transistor action"? (19-18)

16. What does the arrow on the emitter in a transistor symbol indicate? (19-21)

17. In what part of a transistor does the main current flow? (19-21)

18. In figure 114, what circuit element is common to the basic amplifier configuration? (19-25, Fig. 114)

19. What is the letter symbol for emitter current, collector current, and base current in a CB amplifier? (19-27, Fig. 116)

20. What is triggered circuit? (19-29)

21. What is the difference between monostable operation and bistable operation in triggered circuits? (19-35, 40)

22. In reference to figure 118, what two components determine the duration of the triggered pulse? (19-39, Fig. 118)

23. A NOT-AND gating circuit is an example of what basic transistor circuit configuration? (19-56)

CHAPTER 8

Objective: To be able to relate principles of operation and application of electron tubes used in amplifier and electronic power supplies.

1. Name the types of emission and an example of the use of each. (20-11-14)

2. Using figure 123, determine the plate current when the voltage is 20 volts. (20-22; Fig. 123)

3. What is a two-element tube called? A three-element? A four-element? (20-23)

4. What is the advantage of a dual diode over a diode? (20-28)

5. What is the purpose of the control grid in an electron tube? (20-30)

6. Which tube has a screen grid—the triode or the tetrode? (20-36)

7. What electrode in an electron tube eliminates the effects of secondary emission? (20-38)

8. In a gas-filled tube, how is the breakdown voltage determined? (20-42)

9. What is the advantage of a gas diode over a conventional diode? (20-46)

10. What limits the use of a gas-filled VR tube? (20-50)

11. What is the function of the anodes of a CRT? (20-63)

12. Which oscilloscope control has the most effect on the size of the dot on the screen? (20-69)

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13. What is the advantage of using the oscilloscope as a voltmeter instead of using the ordinary AC voltmeter? (20-81)

14. Which axis on the scope is used to represent time? (20-84)

15. What type of rectifier (full-wave or half-wave) is used when high voltage and low current are required? (21-9)

16. Differentiate between a half-wave and a full-wave rectifier, and explain the advantage of one over the other. (21-14)

17. What is the purpose of a power-filter circuit? (21-15)

18. An LC filter circuit with the capacitor connected directly across the rectifier output is called a ______. (21-24)

19. What is the purpose of the bleeder resistor used in a power supply? (21-26)

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20. Why are choke-input filters used in electronic circuits that require considerable power? (21-27)

21. Why is an electronic voltage regulator used in the power supply of figure 151? (21-38)

22. What is meant by the term "cutoff" as applied to vacuum tube plate current? (22-9)

23. Why is it necessary to prevent a triode from operating along the curved part of its characteristic curve? (22-9)

24. What are the two types of amplifier coupling most commonly used? (22-17)

25. What is meant by the term "regenration"? (22-23)

26. Can feedback be used to increase the gain of an amplifier? (22-27)

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CHAPTER 2

1. "Accident prone"–People who generally take a negative approach to safety programs. "Safety conscious"–People who have taken positive action toward safety. (Intro.-2, 3)
2. The propeller is a danger area. (3-4)
3. The intake and exhaust are danger areas in reference to a jet engine. (3-5, 6)
4. Ear plugs should be worn while working around operating jet engines. (3-7)
5. The maintenance instructions (TO) for that helicopter contain the safe approaches. (3-10)
6. One should always be cautious and careful while in the cockpit. (3-13)
7. These hazards come because of the pressure and speed that the system works under. (3-16)
8. In a position to see all around the aircraft. (3-18)
9. Radar beams are extremely hazardous to the eyes. (3-19)
10. You are responsible to yourself and the Air Force concerning knowledge about radioactive materials. (3-21)
11. Good housekeeping is that neatness and cleanliness that is necessary for the successful performance of a job. (4-1)
12. Many fires are started because of carelessness and poor housekeeping. (4-9)
13. Safety is everyone's responsibility. (4-12)

CHAPTER 3

1. The fighter is the aircraft that engages the enemy on the ground and in the air. (5-4)
2. The wing design is one of the most prominent distinguishing features of an aircraft. (5-8)
3. The three wing designs are the conventional, swept, and delta. (5-9-11)
4. The purpose of aircraft designation is to identify each aircraft and its mission. (5-13)

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5. The chord line is often referred to when discussing an airfoil. (6-3)
6. The four aerodynamic forces are lift, gravity, thrust, and drag. (6-4)
7. Relative wind is the direction of airflow with respect to the airfoil. (6-8)
8. The angle of attack is the angle between the relative wind and the chord line of an airfoil. (6-9)
9. An imaginary line passing through the aircraft's center of gravity that is used as a reference for movement. (6-11)
10. The flight axes of an aircraft are longitudinal, lateral, and vertical. (6-12)
11. An aircraft rolls around the longitudinal axis, pitches around the lateral axis, and yaws around the vertical axis. (6-13)
12. The main control surfaces cause the movement around the flight axis. (6-16)
13. The secondary flight control surfaces reduce the force required to move the primary flight control surfaces. (6-21)
14. An alternate source of pressure for hydraulic systems comes from an automatically controlled, motor-driven, AC pump. (7-2)
15. The landing gears are electrically controlled and hydraulically operated. (7-6)
16. The antiskid system prevents wheel skid during landing. (7-7)
17. Electrical requirements are met by AC and DC power supplies and distribution systems. (7-8)
18. The CSD drives the generator at a constant speed. (7-9)
19. Four functions of the AC regulator are to regulate voltage, divide the reactive load, limit current, and rectify the output of the permanent magnet generator. (7-10)
20. The function of the generator control panel is to protect the generator and generator drive. (7-11)
21. No. Tubing color coded with red marking tape indicates it is a fuel line. (8-4)
22. Hydraulic fluids are generally classified as to their type of base. (8-5)
23. Because greases are made to specification, according to operating temperature requirements. (8-14)
24. The most commonly used safety devices are safety wire and cotter pins. (9-3)
25. The common designation of an electreical switch is by the number, poles, throws, and positions they have. (9-8)
26. The rotory selector performs the function of a number of switches. (9-11)
27. Mechanically operated switches are used for limit switches and position indication. (9-12)
28. The thermal switch is used in a fire-warning system. (9-14)
29. Electrically operated switches are called relays. (9-18)
30. The two devices used to control light intensity are the rheostat or the potentiometer. (9-22)
31. The simplest circuit-protection device is the fuse. (9-27)
32. A multimeter is needed to determine the condition of a bakelite fuse. (9-31)
33. Current limiters are generally placed at both ends of a parallel feeder system. (9-33)
34. The advantage of the circuit breaker is that it can be reset. (9-35)

35. The non-trip-free breakers are used in circuits where in-flight emergencies might occur. (9-40)
36. Thermocouple connections are connections that can be soldered. (9-42)
37. Crimp-on terminals require a minimum of time and effort. (9-44)
38. A plug assembly and a receptacle assembly are needed to make an electrical connector. (9-50)
39. Unused pins are filled with wire to provide additional circuits to be included in the connector (9-54)
40. It has high tensile strength, is relatively free from corrosion, and is easy to solder. (9-55)
41. It is generally restricted to large wires for power feeder leads. (9-56)
42. Wire size is designated by a wire gage numbering system. (9-59)
43. Wire should be marked every 15 inches and 3 inches from each end. Wires less than 3 inches need not be marked. (9-64)
44. Wires routed through hot areas should be insulated with high-temperature-resistant material (9-70)
45. Wires bundles must be installed to twist instead of being bent across hinges. (9-74)
46. Wire bundles are laced only when they are inclosed in a junction box. (9-78)
47. Compact wire bundles save weight and space, and require less maintenance. (9-79)
48. Terminal blocks provide a means of connecting terminals inside a junction box or distribution panel. (9-84)
49. Bonding is a fixed union between two metal objects that provides a path for current flow. (9-89)
50. The wire marking machine presses the letter number combinations into the insulation of the wire. (9-93)
51. A soldering iron that is clean and properly tinned is one of the secrets to good soldering. (9-94)
52. Good soldering techniques come with experience. (9-97)
53. The crimping tool has replaced the soldering iron in many cases because it is easier to use and does not require electrical power. (9-98)
54. The jack knife and hand stripper are used to remove insulation from wires. (9-102)
55. The purpose of inspecting the electrical system is to prevent aircraft from being disabled and to prevent flights from being interrupted. (10-2)
56. Technical Order 8-1-1 covers, in detail, the electrical system inspection procedures. (10-4)
57. Wiring should be routed parallel to combustible fluid or oxygen lines and should be a distance of 6 inches from the lines. (10-11)
58. Wire bundles should be supported at intervals of not more than 24 inches. (10-13)

CHAPTER 4

1. *a*. A ammeter is used to measure electron movement.
   b. A voltmeter is used to read a difference in potential.
   c. An ohmmeter is used to read opposition to current flow.
   (Intro. -2)
2. One must know operation and limitations of meters to troubleshoot, service, and maintain electrical systems and equipment. (Intro.-5)
3. The D'Arsonval meter movement is found in most of your test instruments. (11-2)

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4 The turning force is provided by the reaction between a stationary magnetic field and the magnetic field around a DC coil. (11-3)

5. The current flow must always be in the same direction and of the correct polarity. (11-3)

6 Because the movement is rugged, accurate, and capable of measuring DC voltage and current, AC voltage, and resistance. (11-4)

7. The amount of current necessary for a full-scale deflection. (11-5)

8. Damping is the process that eliminates overshooting and the tendency of the pointer to oscillate. (11-6)

9. To prevent an appreciable decrease in circuit current. (11-7)

10. Ammeters are connected in series with the load. (11-9)

11 To measure an unknown current with a multirange ammeter, you should start with the highest range and progress down until a suitable reading is obtained. (11-10)

12. A voltmeter is connected in parallel with a circuit. (11-12, 18)

13 This sets up a shunting action of the meter. (11-21)

14. No permanent magnet is used in the electrodynamometer. (11-22)

15 Overshooting and oscillation is eliminated by means of aluminum vanes that move in inclosed air chambers. (11-25)

16. The ohmmeter's pointer deflection is controlled by the amount of battery current passing through the moving coil. (11-29)

17. The meter should be "zeroed" because of the different resistors for each range. (11-32)

18. An ohmmeter should never be used in a circuit where a voltage already exists. (11-35)

19 Because current passes more readily through the electrolytic capacitor in one direction than in the other. (11-41)

20. A megger is used to measure a large value of electrical resistance. (11-43)

21. In the military application, the megger delivers 500 volts DC. (11-44)

22. A typical multimeter contains voltmeter, milliammeter, and ohmmeter circuits using a single meter movement. (11-51)

23 When a moving-coil meter movement is used to measure AC quantities, the meter circuit must contain a rectifier. (11-54)

24. When a half-wave circuit is replaced with a full-wave circuit, sensitivity is doubled. (11-55)

25. AC meters are calibrated to read rms value. (11-56)

26. A high-resistance voltage divider is used. (11-62)

27. The VTVM is used to measure peak-to-peak values. (11-66)

28. The wattmeter measures elecrical power. (11-69)

29. A very low reading will be obtained from a circuit with a low-power factor. (11-71)

30. The watt-varmeter uses the electrodynamometer type meter movement. (11-73)

31 The power factor of a circuit may be determined by the use of a wattmeter. a voltmeter, and an ammeter. (11-75)

32. The three frequency meters covered in this course are dynamometer type, vibrating reed type, and frequency counter. (11-77-81)
33. The intensity control must be turned down on the oscilloscope to prevent burning the CRT. (12-3)
34. Potentiometers are used to adjust the electron beam. (12-4)
35. The length of the sweep is changed by varying the horizontal gain control. (12-7)
36. The sweep frequency must be known to determine an unknown frequency. (12-11)
37. A smooth curve in which the positive and negative peaks are identical. (12-17)
38. The two tube testers are emission and transconductance. (12-19)
39. The most accurate tester is the transconductance type. A tube may indicate normal emission and still not operate properly. (12-19)
40. To compensate for differences in the line voltage, use the LINE ADJUST knob. (12-21)
41. A small protective lamp is connected in series with the primary transformer. (12-24)
42. The neon lamp will glow continually on one or more switch positions. (12-25)
43. Tapping the tube will cause movement of loose electrodes. (12-26)
44. Excessive gas will be indicated by an increase of more than one scale division. (12-27)
45. The Wheatstone bridge is generally used to measure resistance. (12-30)

CHAPTER 5

1. A machine is a device that helps you do work. (13-2)
2. Mechanical advantage is the ratio of resistance to applied force which measures the efficiency of the machine. (13-4)
3. Three examples of simple machines are the lever, inclined plane, and screw. (13-17)
4. Pressure is the push or pull per unit area of surface acted upon. (13-21)
5. The resistance will decrease. (13-31)
6. The three major particles of an atom are the proton, neutron, and electron. (13-35)
7. A positive ion is one that has a deficiency of electrons. (13-42)
8. The three major electrical categories of materials are insulators, conductors and semiconductors. (13-48)
9. A good conductor is a material that has a large number of free electrons. (13-49)
10. A material is a good insulator when all electrons are held tightly to its orbit. (13-54)
11. As the temperature of a semi-conductor material increases, its resistance decreases. (13-58)
12. The three types of electrical charges are positive, negative, and neutral. (13-61)
13. Like charges will repel each other. (13-62)
14. Static electrical charges are produced by friction, conduction, or induction. (13-67-69)
15. Current flow is the movement of free electrons from negative to positive. (13-73)
16. Voltage is the difference of potential between two points. (13-78)
17. North and south poles. (14-2, 3)

18. By winding it in a coil or by looping it. (14-13)
19. Induction is the process by which electric current is produced within a conductor when moved in a magnetic field. (14-16)
20. A current-carrying conductor will always move at right angles to the field. (14-17)
21. The magnetic field will be strengthened. (14-20)
22. The factors that affect the magnitude of an EMF produced in a generator are the strength of the magnetic field and its relative speed. (14-24)
23. When the voltage rises and falls through 360E°. (14-36, 37)
24. Frequency is the number of cycles in 1 second. (14-38)
25. The frequency of an alternator is determined by the number of poles in the alternator and its speed of rotation. (14-40)
26. The effective value of an AC voltage is rms. (14-44-48)
27. $c = \sqrt{a^2 + b^2}$ (15-8)
28. A maximum value occurs at both 90° and 270° of the sine wave curve. (15-19)
29. The angle is 20°. (15-27)

CHAPTER 6

1. Ohm stated that current through an electrical component is directly proportional to the voltage across the component and inversely proportional to its resistance. (16-5)
2. The mathematical relationship is stated as $I = \frac{E}{R}$. (16-5)
3. An increase in circuit resistance will decrease circuit current. (16-10)
4. Kirchhoff's current law states that the algebraic sum of the currents entering and leaving a junction is zero. (16-15, 16)
5. Kirchhoff's voltage law states that the algebraic sum of the applied voltages and voltage drops around any closed circuit is zero. (16-15, 17)
6. A series circuit is a circuit that has only one path for current flow. (16-21)
7. Total resistance is computed by summing up the individual resistances or, if total voltage and current are known, applying Ohm's law. (16-23)
8. Before you can measure voltages, you must first establish a reference point, otherwise determining polarities would be impossible. (16-26, 27)
9. Total voltage is the sum of the individual voltage drops. (16-29)
10. Power is the product of voltage and current. (16-30)
11. The voltage applied to each path in a parallel circuit is the same and is applied simultaneously. (16 32)
12. Total current is the sum of the currents of each path. (16-38)
13. Total resistance is smaller than the resistance of the path with the least resistance. (16-39)
14. $R_T = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}}$ or $R_T = \frac{R_1 R_2}{R_1 + R_2}$ for two paths. (16-43, 44)

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15. Series parallel circuits can be analyzed by applying the rules for both series and parallel circuits where required. (16-51)

16. A capacitor consists of two plates separated by a dielectric. (17-2)

17. Capacitance is measured in farads. (17-4)

18. Increasing the distance between the plates of a capacitor will decrease the capacitance and vice versa. (17-6)

19. Total capacitance in a series circuit = C_T

$$C_T = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2}} \quad (17\text{-}6)$$

20. Charging current is limited by circuit resistance. (17-14)

21. RC time constant is the measure of how rapidly voltage and current change can respond to changes in voltage current amplitudes. (17-17)

22. There is a 90° phase shift with current leading the voltage. (17-20)

23. Since current is the same in all parts of a series circuit, it is used as the reference point. (17-21)

24. The relationship is determined by elementary vectors. (17-22)

25. The phase angle is computed by trigonometric methods $\Theta = \arc\tan \frac{E_C}{E_R}$ (17-25)

26. Capacitive reactance = $X_C = \frac{1}{2\pi fC}$ (17-27)

27. Impedance is computed by vectors. Impedance = $Z = \sqrt{R^2 + X_C^{\,2}}$ (17-28, 29)

28. By vectors. Total current = $I_T = \sqrt{I_R^{\,2} + I_C^{\,2}}$ (17-33)

29. Total impedance of parallel circuits = Z_T

$Z_T = \frac{Z_1 Z_2}{Z_1 + Z_2}$ where Z_1 and Z_2 is the impedance of each path. (17-33)

30. Reactive power is the power associated with an inductor or capacitor and is returned to the source without doing any work. (17-38)

31. True power is the power associated with the resistive circuit elements and represents the actual rate of doing work. TP is expressed in watts. (17-39)

32. Power factor is the ratio of true power to apparent power and measures the efficiency of the circuit. (17-40)

33. Inductance is that property of a circuit that tends to prevent a change in current. (17-45)

34. Inductance is measured in henrys. (17-46)

35. Parallel inductors are added as parallel resistances

$$L_T = \frac{1}{\frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3}}$$

(17-49)

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36 Time constant: $T = \frac{L}{R}$ seconds. (17-56)

37 The line of reference in a series circuit for both inductance and resistance is current since it is the same in all parts. (17-61)

38. Total voltage in a series circuit is computed by vectors:
$E_T = \sqrt{E_R^2 + E_L^2}$ (17-62)

39. Inductive reactance: $X_L = 2\pi fL$
(17-66)

40. Impedance is computed in the same manner as with series RC circuits by vectors
$Z = \sqrt{R^2 + X_L^2}$ (17-67)

41 The applied voltage vector is used as the reference vector since voltage is the same to each path. (17-72)

42. Reactances are directly added in LCR circuits since they are 180° out of phase. (17-79)

43 To compute impedance in LCR circuits, subtract capacitive reactance from inductive reactance and then use vectors with resistance. (17-79)

44. Resonance occurs when $X_C = X_L$. (17-81)

CHAPTER 7

1. The lagging of magnetic flux behind the magnetic force that produced the flux is hysteresis. (18-11)

2. Saturation is the point of flux density that is maximum for that core. An increase in magnetizing force causes no increase in flux density. (18-16)

3. The AC voltage in the input coil can no longer create a flux change in the core, and therefore there will be maximum output from the amplifier. (18-21; Part A, Fig. 114)

4. The number of turns of wire in each coil. (18-24)

5. A voltage reference is necessary to maintain a constant voltage reference signal (to the first stage of the mag amp) over a wide range of generator output. (18-27)

6 The purpose of the feedback circuits is to detect and damp out the effect of a change in output circuit of a magnetic amplifier. (18-30)

7 A transformer is a device that makes possible the transfer of electrical energy from one circuit to another. (18-34)

8. Energy is coupled from the primary to the secondary by means of the mutual-induction principle. (18-40)

9 The core of soft iron is laminated into very thin strips and each strip is insulated against each other. This prevents iron losses. The windings are as short and as large as possible to reduce copper losses. (18-47, 49)

10. There is one winding in an autotransformer. (18-52)

11 "Acceptor impurities" are those that take on valence electrons to make the semiconductor substance positive. (19-4)

12 "Donor impurities" are those that give up electrons to make the semiconductor substance negative. (19-5)

13. The resistance of the potential barrier is increased to the point where no electrons can flow in the external circuit. (19-7)

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14. The crystalline structure of the transistor will break down and the only opposition to current flow will be the resistance of the material. (19-7)

15. The power gained as a signal is transferred from a low-resistance circuit to a high-resistance circuit. (19-18)

16. It identifies the emitter and indicates the type of transistor, NPN or PNP. (19-21)

17. The main current flows from the emitter to the collector. (19-21)

18. The circuit element that is grounded or common (emitter) to the input circuit and output circuit is common to the basic amplifier configuration. (19-25, Fig. 114)

19. Emitter current, I_e; collector current, I_c; and base current, I_b. (19-27, Fig. 116)

20. A triggered circuit is one in which an externally applied signal causes an instantaneous change in the operating state of a circuit. (19-29)

21. Monostable operation requires only one triggered pulse, while bistable operation requires two triggered pulses. (19-35, 40)

22. The duration of the output or triggered pulse is determined by the values or time constant of R_{F1} and C_{F1}. (19-39, Fig. 118)

23. A NOT AND gating circuit is an example of a common-emitter amplifier. (19-56)

CHAPTER 8

1. Thermionic (vacuum tubes), secondary (none), photoelectric (photo-cell), and cold cathode (gas voltage regulator tube). (20-11-14)

2. The plate current is 9 ma. (20-22, Fig. 123)

3. Diode; triode; tetrode. (20-23)

4. The dual diode serves as a full-wave rectifier, whereas the diode serves as a half-wave rectifier (20-28)

5. The purpose of the control grid is to govern the movement of electrons between the cathode and the plate. (20-30)

6. The tetrode. (20-36)

7. The suppressor grid eliminates the effect of secondary emission. (20-38)

8. The breakdown voltage is determined primarily by the type of gas, the materials used for the electrodes, and their size and spacing. (20-42)

9. In the gas diode, the ionized gas allows more current to flow with less voltage loss, making the gas diode a more efficient voltage regulator. (20-46)

10. The VR tube has a voltage limitation; it is not made for high voltages. However, this can be overcome by connecting them in series. (20-50)

11. The anodes focus the direction of the electrons emitted by the electron gun. (20-63)

12. The focus control has the most effect on the size of the dot on the screen. (20-69)

13. The oscilloscope has a much higher input impedance. (20-81)

14. The horizontal axis represents time. (20-84)

15. Half-wave rectifier. (21-9)

16. In the half-wave rectifier only the positive alternations are passed; in the full-wave rectifier over the full-wave rectifier is that the entire secondary output is rectified, while the full-wave rectifier requires twice the secondary output to provide the same DC output of a half-wave rectifier. (21-14)

17. The power-filter circuit reduces the ripple and delivers a nearly constant direct current to the output terminals. (21-15)

18. Capacitor-input filter. (21-24)

19. The bleeder keeps a load on the circuit and protects the filter capacitors when the tube starts to conduct. (21-26)

20. Choke-input filters provide good voltage regulation. (21-27)

21. The type of electronic voltage regulator used in figure 151 provides a constant output voltage despite changing input voltage and changing loads. (21-38)

22. The "cutoff" is the point at which the potential on the control grid is sufficient to stop current flow through the tube. (22-9)

23. It is necessary to prevent a triode from operating along the curved part of its characteristic curve to prevent grid current from flowing. (22-9)

24. The two types of amplifier coupling most commonly used are the RC and the transformer. (22-17)

25. "Regeneration" is the addition of a portion of the amplified output to the input to increase the gain of the unit. (22-23)

26. Yes, by feeding back some of the output into the input circuit. (22-27)

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STOP– 1. MATCH ANSWER SHEET TO THIS EXERCISE NUMBER. 2. USE NUMBER 1 PENCIL.

42351 01 21

VOLUME REVIEW EXERCISE

Carefully read the following:

DO'S

1. Check the "course," "volume," and "form" numbers from the answer sheet address tab against the "VRE answer sheet identification number" in the righthand column of the shipping list. If numbers do not match, take action to return the answer sheet and the shipping list to ECI immediately with a note of explanation.

2. Note that numerical sequence on answer sheet alternates across from column to column.

3. Use only medium sharp # 1 black lead pencil for marking answer sheet.

4. Circle the correct answer in this test booklet. After you are sure of your answers, transfer them to the answer sheet. If you *have* to change an answer on the answer sheet, be sure that the erasure is complete. Use a clean eraser. But try to avoid any erasure on the answer sheet if at all possible.

5. Take action to return entire answer sheet to ECI.

6. Keep Volume Review Exercise booklet for review and reference.

7. If *mandatorily* enrolled student, process questions or comments through your unit trainer or OJT supervisor.
   If *voluntarily* enrolled student, send questions or comments to ECI on ECI Form 17.

DON'T

1. Don't use answer sheets other than one furnished specifically for each review exercise.

2. Don't mark on the answer sheet except to fill in marking blocks. Double marks or excessive markings which overflow marking blocks will register as errors.

3. Don't fold, spindle, staple, tape, or mutilate the answer sheet.

4. Don't use ink or any marking other than with a # 1 black lead pencil.

Note: The 3-digit number in parenthesis immediately following each item number in this Volume Review Exercise represents a Guide Number in the Study Reference Guide which in turn indicates the area of the text where the answer to that item can be found. For proper use of these Guide Numbers in assisting you with your Volume Review Exercise, read carefully the instructions in the heading of the Study Reference Guide.

Multiple Choice

Note: The first three items in this exercise are based on instructions that were included with your course materials. The correctness or incorrectness of your answers to these items will be reflected in your total score. There are no Study Reference Guide subject-area numbers for these first three items.

1. If I tape, staple or mutilate my answer sheet; or if I do not cleanly erase when I make changes on the sheet; or if I write over the numbers and symbols along the top margin of the sheet,

   a. I will receive a new answer sheet.
   b. my answer sheet will be hand-graded.
   c. I will be required to retake the VRE.
   d. my answer sheet will be unscored or scored incorrectly.

2. The form number of this VRE must match

   a. the form number on the answer sheet.
   b. the number of the Shipping List.
   c. my course volume number.
   d. my course number.

3. So that the electronic scanner can properly score my answer sheet, I must mark my answers with a

   a. number 1 black lead pencil.
   b. ball point or liquid-lead pen.
   c. pen with blue ink.
   d. pen with black ink.

Chapter 2

16 (105) If a person is orderly and presents a good appearance, it will probably

a. be the result of strict parents.
b. result in careless work habits.
c. be reflected in his work.
d. have nothing to do with his work.

17. (104) The part of the body most affected by radar beams is the

a. skin.
b. eyes.
c. nerve system.
d. muscular system.

18. (104) The correct way to isolate a circuit with external power applied to the aircraft is to

a. disconnect the battery.
b. engage the circuit breaker.
c. pull the circuit breaker and tag it.
d. place the switch in the OFF position and tag it.

19. (104) People who are referred to as "accident prone" are generally those who

a. have a negative attitude.
b. have poor work habits.
c. are careless.
d. are all of the above.

20. (104) The man directly responsible for your education regarding radioactive material is

a. you, yourself.
b. the shop supervisor.
c. the maintenance officer.
d. the Chief of Maintenance.

21. (104) The minimum safe distance behind a jet engine exhaust is

a. 100 feet.
b. 150 feet.
c. 250 feet.
d. 200 feet.

22. (104) The propeller of an aircraft is a hazard area. Which one of the following engines does *not* have a propeller?

a. Radial.
b. Turboprop.
c. Turbojet.
d. Reciprocating.

23. (104) The minimum safe distance from a jet engine intake is

a. 25 feet.
b. 35 feet.
c. 55 feet.
d. 75 feet.

24. (104) With an aircraft on jacks for landing gear problems, there should be one man in the cockpit and one on the ground. These two men should be in direct communication. What is the best position for the man on the ground?

a. Near the left wing tip.
b. Near the right wing tip.
c. Where he can see all around the aircraft.
d. Where he can see the man in the cockpit.

Chapter 3

25. (107) On modern high-performance fighters, all control surfaces are actuated through the use of hydraulic pressure. This makes unnecessary the use of

a. balance and servo tabs.
b. air turbine drives.
c. electrical pumps.
d. secondary control surfaces.

26. (106) In the aircraft designation B52G, the G indicates

a. mission-design.
b. aircraft model.
c. series of basic aircraft.
d. current use of basic aircraft.

27. (110) What type of switch operation is normally used with a landing-gear position indicator circuit?

a. Rotary.
b. Thermal.
c. Pressure.
d. Mechanical.

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28. (108) What is the purpose of the constant-speed drive (CSD) used in the O-C power system?

a. The CSD insures constant generator voltage.
b. The CSD insures constant engine and generator speed.
c. The CSD changes variable engine speed to constant generator speed.
d. The CSD changes variable generator speed to constant engine speed.

29. (111) Normally, the only electrical terminals and splices in an aircraft that may be soldered are

a. ignition leads.
b. thermocouple leads.
c. those in exposed areas.
d. those in the engine area.

30. (112) The preferred method for securing electrical terminals on a board is to use

a. a good grade of glue.
b. a castled nut and cotter pin.
c. an anchor nut or self-locking nut.
d. a flat washer and a nonlocking nut.

31. (112) Spot ties are made whenever the bundle supports are more than

a. 6 inches apart.
b. 8 inches apart.
c. 10 inches apart.
d. 12 inches apart.

32. (110) The two most commonly used safety devices on aircraft are

a. cotter pins and safety wire.
b. cotter pins and lockwashers.
c. self-locking nuts and safety wire.
d. self-locking nuts and lockwashers.

33. (107) The purpose of servo tabs on airfoils is to

a. help move the secondary flight control surfaces.
b. help move the primary flight control surfaces.
c. counterbalance pressures on the primary flight controls.
d. counterbalance pressures on the secondary flight controls.

34. (112) One reason for electrical bonding is to provide

a. a common ground for all electrical components.
b. complete isolation of all electrical components.
c. a high-resistance return path for a single-wire electrical system.
d. a low-resistance return path for a single-wire electrical system.

35. (110) Rheostats and potentiometers are both rated with regard to

a. minimum resistance only.
b. maximum resistance only.
c. minimum resistance, current, and power.
d. maximum resistance, current, and power.

36. (113) The quality of a soldered joint depends greatly on the

a. type of iron.
b. type of tip.
c. material being soldered.
d. person doing the soldering.

37. (113) To find the proper temperature setting for a wire-making machine, refer to

a. TO 1-1A-14.
b. TO 1-1A-8.
c. TO 00-20-2.
d. TO 00-20-1.

38. (112) Compact wire bundles are being installed in newer aircraft to

a. save weight and space.
b. make troubleshooting easier.
c. increase current-carrying capacity.
d. provide easy access to individual wires.

39. (108) In an air-turbine-driven hydraulic system, the alternate source of hydraulic pressure is

a. an engine-driven pump.
b. a turbine-driven pump.
c. a three-phase AC motor-driven pump.
d. a three-phase DC motor-driven pump.

40. (111) When replacing a copper terminal, use

a. a copper replacement.
b. an aluminum replacement only.
c. a stainless steel replacement.
d. a steel or aluminum replacement.

41. (114) The conditions that should exist in all aircraft electrical wiring installations are listed in

a. TO 66-1.
b. TO 8-1-1.
c. TO 1-1-8.
d. TO 00-20-2.

42. (112) The electrically resistant oxide film that forms on aluminum surfaces is best removed with

a. Penetrox A.
b. lacquer remover.
c. Stoddards solvent.
d. methyl-ethyl-ketone.

43. (110) The simplest overcurrent protection device is a

a. fuse.
b. switch.
c. current limiter.
d. circuit breaker.

44. (108) The unit that is installed to protect the AC system generator and generator drive is the

a. control panel.
b. voltage regulator.
c. constant-speed drive.
d. governor control system.

45. (112) The tool that is recommended for use when removing insulation from aluminum wire is a

a. hacksaw.
b. jackknife.
c. hand crimper.
d. hand stripper.

46. (111) All MS connectors have aluminum shells *except* one, and it has a

a. steel shell for fire resistance.
b. bronze shell for fire resistance.
c. steel shell for corrosion protection.
d. bronze shell for corrosion protection.

47. (109) Generally, hydraulic fluids are classified according to their

a. use.
b. base.
c. viscosity.
d. temperature range.

48. (112) Instructions for preparing aircraft wire and cable for installation are found in

a. TO 8-1-1.
b. TO 00-20-1.
c. TO 1-1A-14.
d. TO 1-1A-8.

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49. (107) The chord line of an airfoil extends from

a. wing tip to wing tip.
b. wing tip to fuselage.
c. the upper surface to the lower surface.
d. the leading edge to the trailing edge

50. (109) What is the color of the tape that is used to identify fuel lines in an aircraft?

a. Green.
b. Red.
c. Brown.
d. Yellow.

51. (107) The aerodynamic force that opposes forward motion of an aircraft is called

a. lift.
b. drag
c. thrust.
d. weight.

52. (114) When it is necessary to route a wire bundle near a combustible fluid or an oxygen line, the bundle should be

a. protected by a mechanical guard.
b. enclosed in flexible nonmetallic conduit.
c. attached to the plumbing line for support.
d. supported independently of any plumbing line.

53. (107) The flight control surface that primarily controls movement of an aircraft around its lateral axis is the

a. rudder.
b. aileron.
c. elevator.
d. spoiler.

54. (106) Which wing design employs "elevons"?

a. Rotory wing.
b. Swept-wing.
c. Delta wing.
d. Conventional wing.

55. (107) The secondary flight control surfaces that offset a heavy nose or heavy tail condition of an aircraft are the

a. aileron trim tabs.
b. elevator trim tabs.
c. aileron servo tabs.
d. elevator servo tabs.

56. (110) What type of circuit protection device is designed to carry an overload for a short period of time?

a. A heavy-duty fuse.
b. A slow blow fuse.
c. A current limiter.
d. A circuit breaker.

57. (107) Movement of an aircraft around its longitudinal axis is called

a. roll.
b. yaw.
c. slip.
d. pitch.

58. (112) Aluminum wire is sometimes used in aircraft electrical systems because it

a. has less resistance than copper wire.
b. has an ever-present oxide film on its surface.
c. is softer and more flexible than copper wire.
d. weighs less than copper wire of the same size

59. (108) The aircraft main landing gear system discussed in the text is

a. electrically controlled, hydraulically operated, and mechanically locked.
b. hydraulically controlled, electrically operated, and mechanically locked.
c. mechanically controlled, hydraulically operated, and electrically locked.
d. electrically controlled, mechanically operated, and hydraulically locked.

60. (107) The aerodynamic force which results from gravity is often referred to as

a. lift.
b. weight.
c. drag.
d. thrust.

Chapter 4

61. (116) When using an ohmmeter, you should select the multiplication factor (range) that will result in the pointer coming to rest near the

a. midpoint of the scale.
b. lowest point on the scale.
c. highest point on the scale.
d. infinity reading on the scale.

62. (117) The typical multimeter is a combination voltmeter,

a. ammeter, and megger.
b. frequency meter, and dosimeter.
c. wattmeter, and potentiometer.
d. ohmmeter, and milliammeter.

63. (119) Two types of tube testers are commonly used in the Air Force. They are called

a. emission and conductance.
b. transconductance and emitter.
c. emission and transconductance.
d. transconductance and conductance.

64. (115) Damping is accomplished in the electrodynamometer type meter by

a. aluminum vanes.
b. hairsprings.
c. aluminum bobbins.
d. hermetically sealed cases.

65. (119) In order for a galvanometer to read current flow when connected across the two legs of a bridge circuit, the circuit must be

a. inverted.
b. balanced.
c. unbalanced.
d. open-circuited.

66. (118) The sweep frequency controls of an oscilloscope may be used to match the sweep frequency to the

a. saw-tooth generator.
b. input signal frequency.
c. amplitude of the input signal.
d. graduated scale on the screen.

67. (117) A watt-varmeter used on AC powered aircraft indicates

a. apparent load.
b. real load only.
c. reactive load only.
d. reactive and real load.

68. (117) Which frequency meter uses a dial and pointer to provide a visual indication of frequency being measured?

a. Dynamometer type.
b. Vibrating reed type.
c. Frequency counter.
d. Oscilloscope.

69. (118) Movement of the dot from left to right or up and down on an oscilloscope is controlled by the

a. sweep frequency knob.
b. vertical centering knob alone.
c. horizontal centering knob alone.
d. horizontal and vertical centering knobs.

70. (117) Which of the following types of meters *cannot* measure frequency?

a. Counter.
b. Dynamometer.
c. Multimeter.
d. Vibrating reed.

71. (119) When rotating the SHORT TUBE TEST switch, momentary flashes of the neon SHORTS lamp indicate

a. a shorted filament.
b. normal operation.
c. an open tube element.
d. a shorted tube element.

72. (118) Sharp and clear dots or lines on the screen of the oscilloscope are normally obtained by adjusting the

a. intensity and focus knobs.
b. intensity and sweep knobs.
c. focus and sweep knobs.
d. horizontal centering knob.

73. (115) When an unknown voltage is to be measured by a voltmeter, what range should be first selected for use?

a. Mid-meter range.
b. Ohmmeter-set range.
c. The highest meter range.
d. The lowest meter range.

74. (117) What type of meter movement is used in most wattmeters?

a. Hot wire.
b. D'Arsonval.
c. Fixed magnet.
d. Electrodynamometer.

75. (119) The Wheatstone bridge is a network circuit generally used to measure

a. current.
b. voltage.
c. capacitance.
d. resistance.

76. (115) Which, if any, of the following type meters requires a rectifier in order for it to successfully operate on alternating current?

a. D'Arsonval movement.
b. Moving-iron vane type.
c. Electrodynamometer.
d. None of the above.

Chapter 5

77. (120) A positive ion has

a. a deficiency of electrons.
b. an excess of electrons.
c. an excess of neutrons.
d. a deficiency of protons.

78. (122) The frequency of the current produced by a four-pole alternator rotating at 2400 rpm is

a. 60 cps.
b. 80 cps.
c. 160 cps.
d. 380 cps.

79. (122) The value of a DC voltage which will produce the same heating effect as a certain AC voltage is known as the latter's

a. peak value.
b. instantaneous value.
c. effective value.
d. average value.

80. (123) When vectors are 180° out of phase, the resultant is found by

a. dividing the larger by the smaller.
b. dividing the smaller by the larger.
c. subtracting the smaller from the larger.
d. multiplying the larger by the smaller.

81 (123) At which of the following angles is the sine at its maximum value of 1?

a. 0°.
b. 90°.
c. 180°.
d. 360°.

82. (120) A significant fact about the continuous cable in the fire warning system is that as temperature

a. decreases, resistance between the conductors decreases.
b. decreases, the current between the conductors increases.
c. increases, the current between the conductors decreases.
d. increases, resistance between the conductors decreases.

83. (122) Moving a conductor within a magnetic field so that lines of force are cut will

a. produce a current in the conductor.
b. change the resistance of the conductor.
c. not affect the conductor's electrical state.
d. increase the strength of the magnetic field.

84. (123) If the two legs of a right triangle are 9 inches and 12 inches long, respectively, what is the length of the hypotenuse?

a. 15 inches.
b. 17 inches.
c. 19 inches.
d. 21 inches.

85. (122) If a voltage has a peak value of 150 volts, what is its average value?

a 75 volts.
b. 95.55 volts.
c. 106 volts.
d. 212 volts.

86. (120) Pressure is usually measured in

a. ounces per unit volume.
b. feet per cubic unit.
c. pounds per unit volume.
d. pounds per unit area.

87. (120) What is the approximate theoretical mechanical advantage of a screw jack with a 30-inch handle if the pitch of the threads is ½ inch?

a. 30.
b. 60.
c. 190.
d. 375.

88. (120) A proton has what type of electrical charge?

a. A negative charge.
b. A positive charge.
c. A neutral charge.
d. It may have either a positive or negative charge.

89. (121) A difference in electrical potential between two points is referred to as

a. conductance.
b. resistance.
c. current.
d. voltage.

Chapter 6

90. (124) According to Ohm's law,

a. current is inversely proportional to voltage.
b. current is directly proportional to voltage.
c. voltage is inversely proportional to resistance.
d. resistance is directly proportional to current.

91. (125) Thirty volts is applied to a circuit consisting of a 5-ohm, a 10-ohm, and a 15-ohm resistor connected in parallel. Which of the following is a correct statement?

a. The current through the 5-ohm resistor is greater than the current through the 10-ohm resistor.
b. The voltage drop across the 15-ohm resistor is greater than the voltage drop across the 10-ohm resistor.
c. The total resistance of the circuit is greater than 5 ohms.
d. The voltage drop across the 15-ohm resistor is less than the voltage drop across the 10-ohm resistor.

92. (127) A power factor of 100 percent in an electrical circuit indicates that the circuit is probably

a. resistive in character.
b. capacitive in character.
c. inductive in character.
d. reactive in character.

93. (125) A circuit has a 5-ohm, a 10-ohm and a 15-ohm resistor connected in series. With an indication of 2 amperes flowing through the 5-ohm resistor, there must be

a. an applied voltage of 30 volts.
b. an applied voltage of 60 volts.
c. a 15-volt drop across the 15-ohm resistor.
d. a 20-volt drop across the 5-ohm resistor.

94. (129) In the analysis of parallel LR circuits, the reference vector is usually the

a. total current.
b. applied voltage.
c. current through the resistance.
d. voltage of the capacitor.

95. (124) A general application of Kirchhoff's current law is that

a. electrical charge is not conserved.
b. current is inversely proportional to voltage.
c. current is instanteous at all points in a closed single loop.
d. current varies somewhat at different points in a closed single loop.

96. (128) Inductance in an electrical circuit

a. resists change.
b. lowers resistance.
c. creates magnetism.
d. augments current.

97. (126) The capacitor changing current in an RC direct-current circuit is governed by

a. capacitor size.
b. circuit resistance.
c. voltage drop.
d. battery resistance.

98. (127) The total current in a parallel RC circuit that has 0.4 ampere flowing through the capacitance and 0.3 ampere flowing hrough the resistance is approximately

a. 0.3 ampere.
b. 0.4 ampere.
c. 0.5 ampere.
d. 0.7 ampere.

99. (124) When applying Kirchhoff's voltage law, the direction of current flow

a. is not a factor for consideration.
b. is assumed to be from positive to negative.
c. is assumed to be from negative to positive.
d. may be assumed to be in either direction.

Chapter 7

100. (132) The electrical potential barrier of a transistor can be increased by

a. the doping process.
b. increasing reverse bias.
c. decreasing forward bias.
d. increasing the potential.

101. (134) Gating circuits function primarily as

a. heaters.
b. switches.
c. rectifiers.
d. amplifiers.

102. (132) In a PN junction rectifier, the cathode is normally the

a. P region and the N region is the anode.
b. P region and the junction is the anode.
c. N region and the P region is the anode.
d. junction and the N region is the anode.

103. (132) N type materials used in semiconductors have an excess of

a. ions.
b. holes.
c. protons.
d. electrons.

104. (132) A rectifier power supply using four PN junction diodes is a

a. full-wave bridge.
b. half-wave bridge.
c. semiwave conventional.
d. half-wave conventional.

105. (130) A magnetic amplifier

a. augments voltage.
b. amplifies current.
c. increases magnetism.
d. controls power.

106. (134) NOR gating circuits are best operated as

a. common base.
b. common emitters.
c. common collector.
d. none of the above.

107. (130) The term used in magnetic circuits which corresponds to the term "voltage" in electrical circuits is

a. flux.
b. reluctance.
c. magnetomotive force.
d. magnetic lines of force.

108. (132) A diode that is specifically designed to operate with reverse bias is the

a. gas diode.
b. SCR diode.
c. tunnel diode.
d. Zener diode.

109. (131) Most transformers use iron-core material because it

a. offers a path of low reluctance.
b. offers a path of high ~~reluctance.~~
c. reduces the effect of eddy currents.
d. increases the effect of eddy currents.

Chapter 8

110. (137) In the cathode-ray tube, the positioning of the electron beam is controlled by adjusting the

a. voltage applied to the first grid.
b. voltage applied to the deflecting plates.
c. voltage applied to the first and second anodes.
d. velocity at which the electrons pass through the tube.

111. (135) In a triode, primary plate current flow is determined by varying the signal to the

a. plate.
b. cathode.
c. control grid.
d. screen grid.

112. (137) If the polarity of the top vertical deflection plate is made positive and the bottom vertical deflection plate is made negative, the beam and spot will

a. move up.
b. move down.
c. not move.
d. move diagonally.

113. (140) Undesired grid current is avoided in an electron tube by placing a

a. negative bias on the grid.
b. positive bias on the grid.
c. positive bias on the plate.
d. negative potential on the plate.

114. (135) The process by which a heated emitter gives off electrons is called

a. the Hertz effect.
b. the Edison effect.
c. thermionic emission.
d. photoelectric emission.

115. Which element of a cathode-ray tube is responsible for bending the electron stream?

a. The grid.
b. The first anode.
c. The second anode.
d. The deflection plates.

116. (136) Grid control is reestablished in a thyratron tube by

a. reducing grid voltage.
b. increasing grid voltage.
c. raising plate potential.
d. reducing the plate potential.

117. (135) In a pentode tube, the effects of secondary emission are eliminated by

a. the use of a suppressor grid.
b. the use of a screen grid.
c. reducing the electron flow to the plate.
d. reducing the amplification factor of the tube.

118. (135) In an electron tube, electrons normally flow from the

a. plate to the grid.
b. grid to the cathode.
c. cathode to the plate.
d. plate to the cathode.

119. (140) Feedback is useful in

a. raising the output of the amplifier.
b. lowering the output of the amplifier.
c. stabilizing the output of the amplifier.
d. none of the above instances.

120. (140) The grid in a triode tube has greater effect on the emitted electrons than the plate does because the

a. grid is hotter than the plate.
b. plate is hotter than the grid.
c. plate is larger and thicker.
d. grid is closer to the cathode.

121. (138) To provide good regulation under varying load conditions, a power supply should contain a

a. full-wave rectifier and a choke-input filter.
b. half-wave rectifier and a choke-input filter.
c. full-wave rectifier and a capacitance-input filter.
d. half-wave rectifier and a capacitance-input filter.

122. (138) Half-wave rectifiers are generally used when the power requirements are for

a. low voltage and low current.
b. high current and low voltage.
c. high current and high voltage.
d. high voltage and low current.

123. (140) The signal voltage applied to the grid or any tube should be of limited value. If this value is exceeded, the result is

a. a burned out tube.
b. excessive plate to grid current.
c. distortion in the output signal.
d. all of the above.

124. (137) If an AC signal is applied to the vertical deflection plates of an oscillescope, without the application of sweep, the spot will appear

a. as a horizontal line.
b. to decrease in intensity.
c. as a vertical line.
d. to make jerking movements.

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AIRCRAFT ELECTRICAL REPAIRMAN

(AFSC 42350)

Volume 2

Aircraft Power Systems

Extension Course Institute

Air University

2-1

Preface

NOW YOU are ready for Volume 2 which will discuss the aircraft power systems. These systems are the nerve center of the aircraft, because they serve as the source of energy or control for almost every system on any aircraft. You, the electrical repairman, have the responsibility for these power systems.

In Chapter 1 we will discuss the lead-acid and alkaline batteries, methods of servicing, and the equipment used for servicing. The importance of batteries should not be underestimated, because they are very important as emergency power systems. Their maintenance is very critical and a well operated battery shop has more the appearance of a laboratory than a shop.

In order to maintain the very essential ac and dc power systems, an electrical repairman has to use many different types of test equipment. In Chapter 2 you will learn the T31, T35, T170 testers; the MC–2 Basic Field Test Stand; the A–1 Load Bank; and the L–1A Inverter Test Stand. These are not by any means the only type test equipment you will be concerned with, but they are the most common and usually can be found in most shops. Most of the other testers are designed for one weapon system only and will be taught with that weapon. Your knowledge and use of these testers will play a large part in how effectively you troubleshoot.

Chapter 3 is devoted to the operation, maintenance, testing, and troubleshooting of the dc generator system and components. The knowledge gained from this chapter will be a great asset to you in your daily work as an electrical repairman.

In modern aircraft, the use of the transformer-rectifier (T-R unit), in addition to or in lieu of the dc generator, is becoming more and more common. In Chapter 4 we will discuss the various types of T-R units you will encounter. You will be given a description of a typical T-R power system.

On most all aircraft the ac generator system is important, and on many aircraft it is the original source of all electrical energy with the exception of the battery. Chapter 5 will discuss the operation, maintenance, testing, analysis, and troubleshooting of the ac generator systems.

The last chapter of this volume will deal with motors (both ac and dc) and inverters (both rotary and static). Because motors and inverters are covered last in this volume does not mean that they are of lesser importance. There are many motors on all aircraft and most all aircraft have some type of inverter.

Printed and bound in the back of this volume are three foldouts. Whenever you are referred to one of these foldouts in the text, please turn to the back of the volume and locate it.

If you have questions on the accuracy or currency of the subject matter of this text, or recommendations for its improvement, send them to TECH TNG CEN (TSOC) CHANUTE AFB ILL 61868.

If you have questions on course enrollment or administration, or on any of ECI's instructional aids (Your Key to Career Development, Study Reference

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Guides, Chapter Review Exercises, Volume Review Exercise, and Course Examination), consult your education officer, training officer, or NCO, as appropriate. If he can't answer your questions, send them to ECI, Gunter AFB, Alabama 36114, preferably on ECI Form 17, Student Request for Assistance.

Material in this volume is technically accurate, adequate, and current as of April 1973.

Code numbers appearing in the lower right-hand corner on figures are for preparing agency identification only.

This volume is valued at 39 hours (13 points).

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Contents

Aircraft Batteries and Servicing Equipment

IF A DIRECT current is passed through a lead acid storage cell in a direction opposite to that which it takes when the cell is discharging, which of the following will happen?

a. Cell will be discharged.
b. Sulphuric acid will become less concentrated.
c. Cell's electrical energy will be decreased.
d. Specific gravity of the cell will be increased.

2. About 70 percent of the basic electrical course graduates select the wrong answer when asked the above question. What answer do you consider correct? If you have *not* chosen "d" you have just increased the percentage of school graduates who do not understand what happens to the electrolyte during the charging and discharging of a lead-acid battery.

3. In tech school you learned the theory of battery operation, servicing, charging, repairing, and testing. We will accept this theory, expand upon it and in this chapter, present the knowledge you need to actually perform these jobs. The types of batteries we will discuss here are the lead-acid, nickel-cadmium and silver-zinc batteries.

1. Lead-Acid Batteries

1-1. The lead-acid battery gets its name from its construction. It has cells that contain lead plates. The plates are immersed in an electrolyte solution which contains sulphuric acid.

1-2. The open-circuit voltage of a lead-acid cell—its voltage when there is no load on it—is approximately 2.2 volts. This voltage is the same for every lead-acid cell, regardless of its plate size. It remains at this value until the cell is practically dead, regardless of its state of discharge. However, the area of the plates determines the length of time that the cell will deliver its rated current.

1-3. During charge, electrical energy is converted to chemical energy, which is stored in the cell. During discharge the chemical energy is reconverted to electrical energy. The net result is the same as if electricity were actually stored in the cell. In the charging process, current is forced into the cell in a direction opposite to that in which it flows when the cell is discharging to a circuit.

1-4. The purpose of the aircraft storage battery is to provide an emergency source of electrical power. The service life of a battery depends a great deal upon the frequency and quality of care it is given. Batteries that are abused or receive careless treatment and servicing, generally have their service life ended prematurely. It is your responsibility to know the correct maintenance procedures and to provide the service and care necessary to maintain a serviceable battery. Safety first always, is the first lesson to learn when working with batteries.

1-5. **Safety.** Forget safety just once in the battery shop and you can seriously hurt yourself or your teammate as there are many safety hazards of which you should be aware. The greatest is the sulphuric acid used in the electrolyte.

1-6. *Sulphuric acid.* Sulphuric acid can cause painful burns if it contacts your hands or other parts of your body. Get it in your eyes and it can blind you. Whenever you are handling or mixing electrolyte, be very careful; wear goggles or a face shield, a rubber apron, rubber acid-proof gloves, and rubber boots. If you should accidentally spill or splash some electrolyte on you, you can neutralize it by flushing with large quantities of fresh water or a solution of bicarbonate of soda (baking soda) in water. You should always have a quantity of this solution mixed and available when you are servicing lead-acid batteries. OBTAIN MEDICAL ATTENTION AT ONCE.

1-7. A fresh water supply can be provided in many forms. It can be just a hose connected to a water tap or, in a large battery shop, a deluge shower and eye wash. If you ever have to use the deluge shower, remember speed is what

Cartoon 1. Al in the shower.

counts; don't waste time taking off your clothes. The faster you get under the shower and wash away and neutralize the electrolyte, the less you may be burned. If you have a deluge shower and eye wash located in your shop, do you know how they work? Better yet, do they work? Can you get to the deluge shower and eye wash without tripping over batteries or servicing equipment? Can you get to them with your eyes closed? If you answer "no" to any of these questions, a safety hazard exists and needs your attention.

1-8. *Hydrogen gas.* Hydrogen gas is another hazard to safety in the lead-acid battery shop. It is produced by the charging batteries, and is a colorless, odorless, highly flammable gas. You'll never know it's there until it's too late. Take every precaution to eliminate sparks in this area. It only takes one spark to ignite hydrogen gas and put you out of a job. Here are a few precautions:

a. Turn off the charging units before connecting or disconnecting a battery to a charger.

b. Don't smoke. If someone enters the shop with a lit cigarette, tell him to put it out and then tell him why.

c. Remove all jewelry while working. Get a ring or a watch band shorted across a battery and the sparks will fly.

The battery shop has many safety hazards. It is up to you to recognize them and to take positive preventive action so that foolish accidents don't hinder your operation.

1-9. **Shop Operation.** In the following paragraphs, we will consider general information and common jobs of the battery shop technician. We will not go into the location and facilities because lead-acid battery shops range from plush, air conditioned buildings to two-by-four shacks in back of hangars. They are equipped to handle from one to hundreds of batteries at a time. But, regardless of shop location or the number of batteries that can be serviced, the servicing procedures remain the same. Detailed information for servicing lead-acid batteries and detailed shop procedures is found in the applicable TO's. In the following paragraphs, we will discuss only the general information that pertains to all batteries.

1-10. *Battery ratings!* The voltage of a battery is determined by the number of cells that it has connected in series. Although the open-circuit voltage of a lead-acid cell is approximately 2.2 volts, the cell is normally rated at only 2 volts because it drops to that value under load. A battery rated at 12 volts consists of 6 lead-acid cells connected in series, and a battery rated at 24 volts has 12 cells.

1-11. Storage battery capacity (size) is expressed in terms of ampere-hours. This rating indicates how long the battery may be used at a given rate before it becomes discharged. Theoretically, a 100 ampere-hour battery furnishes 100 amperes for 1 hour, 50 amperes for 2 hours, or 20 amperes for 5 hours. Actually, the ampere-hour output of a particular battery depends upon the rate at which it is discharged. Heavy discharge currents tend to heat the battery and decrease its ampere-hour output. For aircraft batteries, a period of 5 hours has been established as the discharge time in rating battery capacity. However, this period of 5 hours is only a basis for rating and does not necessarily mean the length of time during which the battery is expected to furnish current. The efficiency and the ampere-hour output are greatly reduced when the battery is discharged at a high rate. Under actual service conditions the battery can be completely discharged within a few minutes, or it may never be discharged if the generator provides sufficient charge.

1-12. The ampere-hour capacity of a cell depends upon its total effective plate area. Thus, connecting a number of positive and negative plates within a cell increases the total effective plate area and the capacity of the cell. Connecting cells in parallel increases the total ampere-hour capacity. In aircraft using more than one battery, the batteries are usually connected in

parallel. The total voltage is equal to that of one battery, but the ampere-hour capacity is increased; total capacity is the sum of the ampere-hour ratings of the individual batteries.

1-13. *Electrolyte.* The electrolyte used in lead-acid batteries is a mixture of sulphuric acid and water. The specific gravity of such a mixture ranges from 1.275 to 1.300. The specific gravity of a liquid is its comparative weight with respect to an equal volume of water. Water has a specific gravity of 1,000; therefore, an electrolyte mixture of 1.275 is 1.275 times as heavy as water.

1-14. Electrolyte for lead-acid storage batteries, issued by the Air Force, is a 1.400 specific gravity solution of sulphuric acid and water. Concentrated commercial grade sulphuric acid has a specific gravity of 1.835. Either the 1.400 or 1.835 specific gravity sulphuric acid must be mixed with distilled or drinking water to lower it to the proper specific gravity for filling batteries, 1.275 to 1.300.

1-15. If you ever have to mix electrolyte, be very careful and remember to wear the protective clothing provided. When you mix the acid with the water, heat is generated chemically. Did you ever see someone pour water into a hot frying pan? What was the result? If you pour water into the sulphuric acid it would splatter the same way. This is why you must always pour the sulphuric acid into the water, and do so very slowly. The mixing container for the electrolyte should be glass, earthenware, lead-lined wood, or a similar container that is resistant to the action of the sulphuric acid. It must also withstand the heat generated during the mixing period.

1-16. *State of charge.* The state of charge of a lead-acid battery is determined by measuring the specific gravity of the electrolyte with a hydrometer. Remember, the electrolyte is a mixture of water and sulphuric acid with a specific gravity of 1.275 to 1.300. As the battery discharges, the sulphuric acid is absorbed from the electrolyte. Now look back at the introductory test question as seen in the correct answer "d", when the battery is being charged, the charging current forces the sulphuric acid out of the plates and the specific gravity of the electrolyte increases. In reality, the hydrometer measures the amount of sulphuric acid in the electrolyte, and indicates the amount as a specific gravity reading. From this reading you can determine the state of charge.

1-17. The type of hydrometer that you will probably be using is the temperature-correcting hydrometer shown in figure 1. The depth to which the hydrometer bulb sinks into the electrolyte sample is determined by the density of the electrolyte. The scale value indicated at the level of the electrolyte on the hydrometer is the specific gravity. When a hydrometer is in use, the float should float upright in the enclosed tube. If the float leans against the sides of the tube, an inaccurate reading will result. Extract only enough electrolyte from the cell to cause the float to rise. If too much electrolyte is removed, the float will hit the top and a lower than actual specific gravity reading will be indicated. A new fully charged battery should have a specific gravity reading of 1.275 to 1.300. A

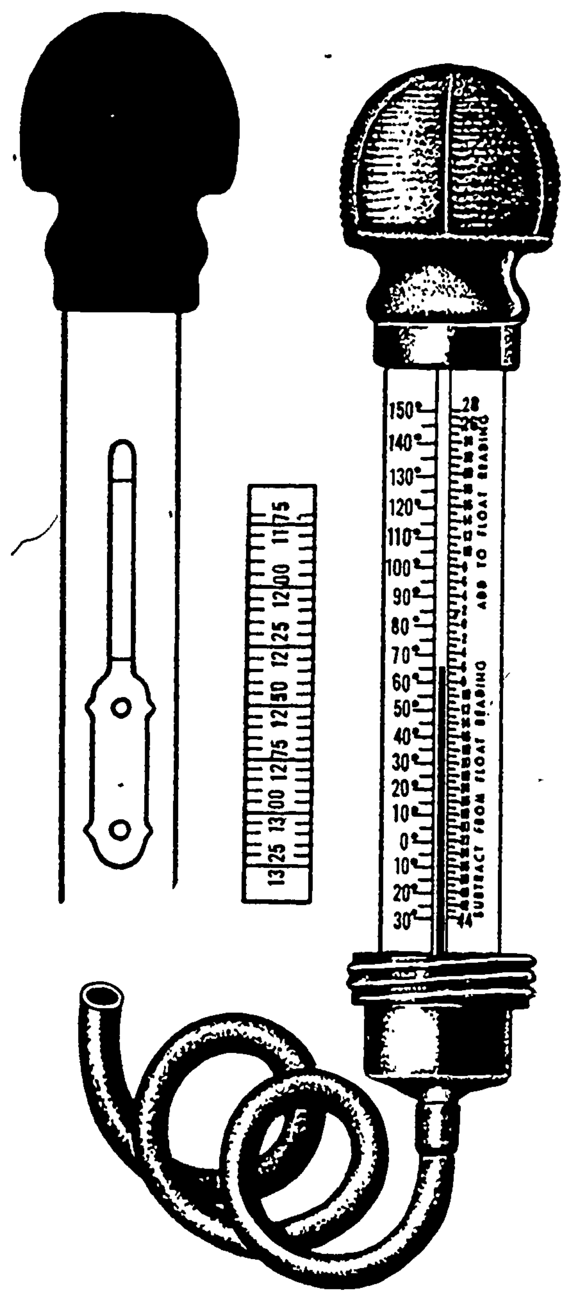


Figure 1. Temperature correcting hydrometer.

specific gravity reading between 1.275 and 1.300 indicates a high state of charge; from 1.240 to 1.275, a medium state of charge; and below 1.240, a low state of charge. Batteries must be recharged if their specific gravity is below 1.240.

1-18. You should remember that the concentration of the electrolyte alone is not the cause of the particular state of charge of a cell. Sulphuric acid could be added or the electrolyte entirely replaced in a discharged battery, but the plates would remain in their discharged condition. The specific gravity test is only reliable if nothing has been added to the electrolyte except occasional small amounts of distilled water to replace that water lost due to normal evaporation.

1-19. You should make the hydrometer test before adding any water to the electrolyte in a cell. This precaution is necessary because the

TABLE 1
TEMPERATURE-CORRECTION TABLE

Electrolyte Temperature F°.	Correction Points	Action
140	24	
130	20	
120	16	Add to the hydrometer reading
110	12	
100	8	
90	4	
80	0	
70	4	
60	8	
50	12	
40	16	Subtract from hydrometer reading
30	20	
20	24	
10	28	
0	32	
-10	36	
-20	40	
-30	44	

water is lighter than the electrolyte and will tend to float on top of the electrolyte in the cell. Therefore, if you make a hydrometer test immediately after adding water, the hydrometer syringe will suck up a sample which will not give true indication of the electrolyte condition. Appreciable time is required for the water to mix with the electrolyte; to speed up the mixing process the battery may be discharged and recharged.

1-20. Since temperature affects the density of the electrolyte, you must always consider it when you check the specific gravity of the electrolyte. The temperature-correcting hydrometer, as shown in figure 1, includes a thermometer which indicates the temperature of the electrolyte at the same time you are checking its density. This permits you to apply an immediate correction to get a corrected specific gravity reading. The correction points are listed in table 1.

1-21. Look at table 1. Note that 80° F. is used as a reference point. For every 10° above 80° you add 4 points to the specific gravity reading, while for every 10° below 80° you subtract 4 points. What would the specific gravity reading of a battery be if you took a reading and the hydrometer indicated 1.250 and the temperature was 50° F.? Look at the temperature correction table. For 50° F. we would subtract what? 12 points is right. Your original reading of 1.250 minus 12 points now equals 1.238. This tells you that the battery is in a low state of charge. Remember we have already stated that a battery with a specific gravity reading below 1.240 is in a low state of charge.

1-22. *Servicing.* Before you place a battery on charge, you must do several things to it. The first step is to clean the outside of the case and the top of the battery cells with a small hose and plenty of fresh water. Neutralize any acid on the battery with a solution of bicarbonate of soda. You should remove all corrosion by scraping or brushing the surface clean with a nonmetallic brush. Then remove all traces of acid film from the connections or terminals, using a cloth that has been dampened with a soda solution. After this treatment, cover the metal surfaces with a light film of pure vaseline to protect them from future acid action. Why vaseline? Ordinary greases contain an animal or vegetable fat which is more corrosive than the battery electrolyte, but vaseline does not corrode. Dry the tops of the cells with a sponge to pick up any surplus moisture. Always keep them dry because dampness or dirt permits electric currents to leak away over the surface between the terminals.

1-23. Remove the vent plugs and inspect the electrolyte level. Ordinarily, the only loss in volume of the electrolyte is from the loss of its water. While some water is lost by evaporation, most of the loss is due to the action of the charging current which decomposes the water, forming gases which are given off through the vent plugs. Acid is never lost from the battery by evaporation or decomposition. Therefore, it should never be necessary to add new electrolyte unless some should get outside of the cell through carelessness. If the level of electrolyte is low, add distilled water to bring the level to approximately three-eights of an inch above the protector on top of the separators. You should use only water which is free from impurities in storage batteries. The presence of impurities in the battery causes local actions that tend to discharge the surrounding area of the plate.

1-24. Add water with a self-leveling syringe as shown in figure 2. Draw a supply of water into the rubber bowl of the syringe; insert it into the cell; then inject a little water into the cell by

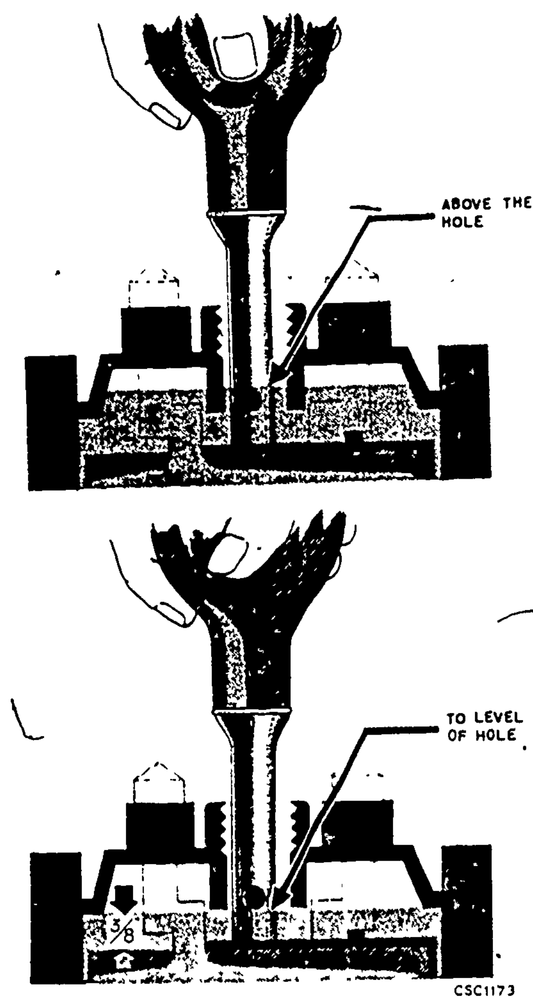


Figure 2. Self-leveling syringe.

squeezing the rubber ball. When you release the pressure on the ball, the surplus fluid returns to the ball. In order to establish the correct level of electrolyte in the cell, there is a small hole drilled through the stem of the syringe. When the fluid level is lowered to the edge of the hole, the return of fluid into the syringe stops and the level of the electrolyte is correct.

1-25. While you are charging the batteries, unscrew the vent caps and leave them in place over the cell openings so that electrolyte gas and spray does not form over the top of the cells. Also, when the caps are in place, foreign material does not fall into the cells.

1-26. **Battery Charging Methods.** You charge a storage battery by passing a direct current into the battery in a direction opposite to that of the discharge current. Because of the resistance within the battery, the voltage of the charging source must be greater than the open-circuit voltage of the battery. For example, the open-circuit voltage of a fully charged, 12-cell, lead-acid battery is approximately 26.4 volts (12×2.2 volts). Therefore, a minimum of approximately 28 volts is required to charge it. This larger voltage offsets the voltage losses in the battery due to internal resistance. You can charge batteries by one of two methods, the constant-current method, or the constant potential method.

1-27. *Constant-current method.* In this method of charging, the *current* is maintained at a predetermined value throughout the entire period of charge. The recommended charging rate for aircraft batteries is determined by the manufacturer. TO 8D2-1-31, *Operating and Service Instructions, Aircraft Storage Batteries and Venting Systems,* contains a table which lists the charging rates of most lead-acid batteries used by the Air Force. The table lists the charging rates for new batteries (initial charge), as well as for batteries which have been in service and are in the shop for normal charging.

1-28. There may be a time when you are required to charge a battery which is not listed in the TO. What charging rate should you use? A general rule to use in a case like this is to charge the battery at a rate which is 10 percent of the ampere-hour capacity of the battery. For an example if you had to charge a 44 ampere-hour battery, you could charge it at 4.4 amps. You should use this rule only when you cannot find the battery listed in a TO.

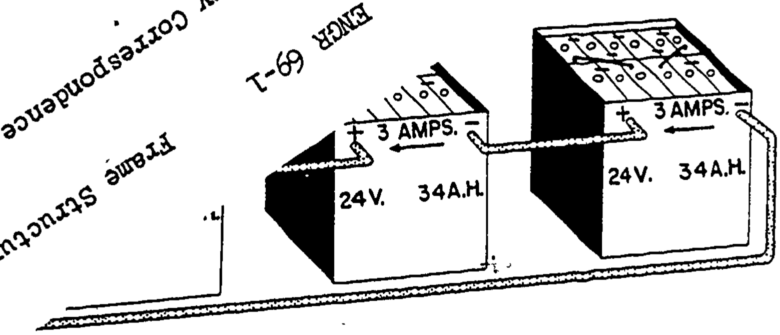
1-29. Fortunately, it is not necessary to have a separate charger for each battery undergoing charge. Some constant-current charging installations have a separate charging outlet for each battery, as well as an entirely separate set of manual controls. With this type of installation, you can adjust the individual charging rate of each outlet to the requirement of the individual battery. The most frequently used constant-current charger in service today is the bulb type charger. This unit can charge as few as 3 cells (a 6-volt battery) at the minimum charging rate required (1 ampere), or as many as 36 cells (three 24-volt batteries) in series at the maximum rate of 6 amperes at one time.

Cartoon 2. Shock treatment.

1-30. This charger requires little maintenance. The most common malfunction that you will encounter is a burned out rectifier bulb. You can replace the bulb very easily by following the procedures in the applicable TO. A word of caution: always disconnect the charger from the power source before performing any maintenance.

1-31. When you charge batteries by the constant-current method, connect them in series, as shown in figure 3. Connect the positive terminal of one end battery to the positive terminal of the charger; connect the negative terminal of the opposite end battery to the negative terminal of the charger. After you complete the connections, place the charger in operation and rotate the manual adjustment until the ammeter gives a charging indication. Batteries can be and have been connected backwards. If this ever happens to you, take this action: Discharge the battery at a slow rate and recharge it correctly. *The charging current is determined by the ampere-hour capacity of the smallest capacity battery in the string.*

1-32. If you wire in series batteries of 11-ampere-hour, 17-ampere-hour, and 34-ampere-



. Constant-current charging; batteries of same capacity.

..e group for charging, you ..ging rate for 1.1 amperes (the n . charge rate of the 11-ampere-hour ba.. The 11-ampere-hour battery would then ..e charging at its normal service charge rate. However, the 17-ampere-hour and 34-ampere-hour batteries would be charging at reduced rates. This reduced rate would increase their charging times considerably and decrease the efficiency of the charging equipment. This is why in most battery shops, it is a common practice to place batteries of the same capacity together in one charging string so that maximum charging may be accomplished with the equip-

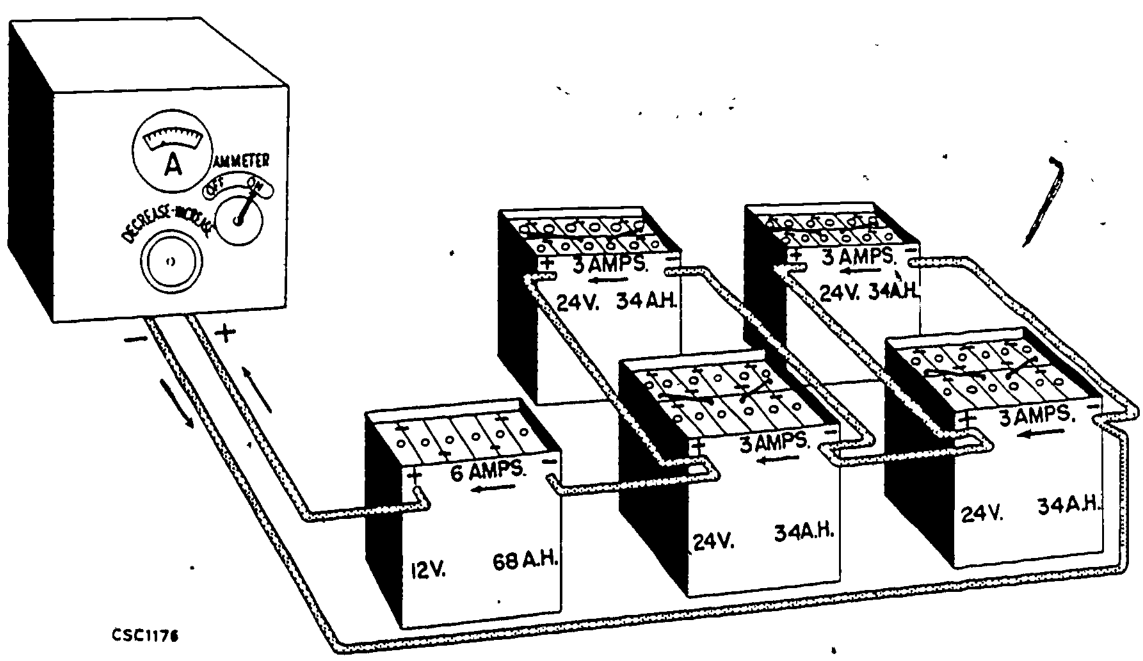


Figure 4. Constant-current charging; batteries of different capacities connected in parallel and in series.

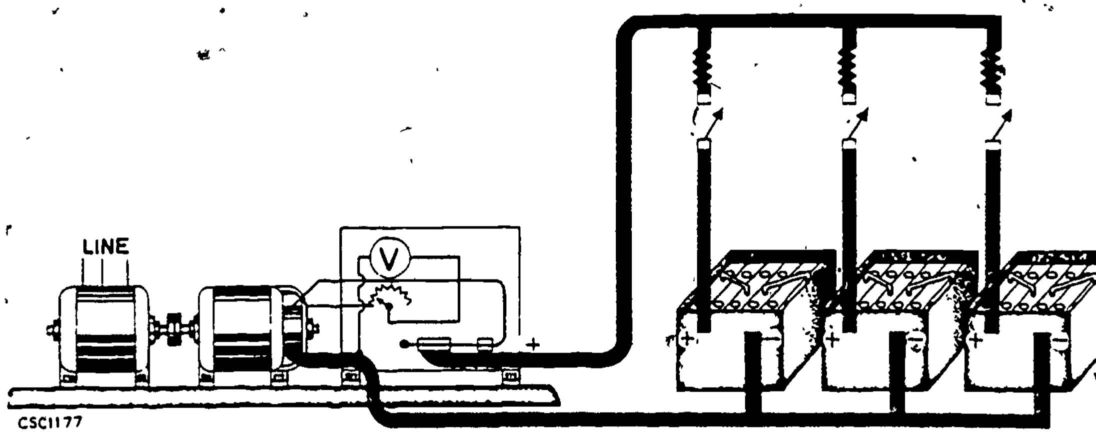


Figure 5. Constant-potential charging.

ment available. When charging batteries of different capacities, you may connect two smaller capacity batteries having similar voltage and capacity in parallel, and then connect the charging circuit in series with a larger capacity battery. A setup of this type is shown in figure 4. You may connect many different combinations of batteries of various sizes in this manner to make more efficient use of the charger.

1-33. You can figure the approximate charging time of a completely discharged battery by dividing the ampere-hour capacity of the battery by the charging rate. An example of this would be a battery which has a 34 ampere-hour capacity and a charging rate of 2.5 amps. Dividing 34 by 2.5 would give you an approximate charging time of 13½ hours.

1-34. *Constant-potential method.* In this method of charging, you maintain the voltage at a predetermined value throughout the entire period of charge. The recommended charging rate is 14 volts for 12-volt batteries, and 28 volts for 24-volt batteries. The charging source can be a motor-driven generator, a dc generator test stand, or a rectifier. Connect the batteries to be charged in parallel to the charging source, as illustrated in figure 5. Each battery automatically draws a current according to its state of charge and its ampere-hour capacity. The charging rate at the start of charge is somewhat higher than normal, but the rate decreases gradually as the battery becomes charged.

1-35. Most constant-potential chargers in use today provide only a 28-volt charging source. With this in mind, how do you charge 12-volt batteries? To do this you connect two 12-volt batteries of the same ampere-hour rating in series, and then connect the series string in parallel with the source.

1-36. *Attention during charge.* You must inspect batteries undergoing charge at certain time intervals. You should take specific gravity readings of the positive-end cell of each battery. Take the first specific gravity reading after 4 hours of charging, and then every 2 hours. Keep a record of these readings. When two successive readings show no increase in the specific gravity, remove the battery from the charging line, as it has reached its maximum state of charge. Remember, as we stated previously, you must check all readings for temperature corrections.

1-37. As a battery charges, gas bubbles rise to the surface of the electrolyte. This is a normal condition. But what is happening when the electrolyte appears to be boiling violently? Either you have charged the battery too long, or charged it at an excessively high rate. What should you do? If the battery is fully charged, remove it. If the charging rate is too high, reduce it.

1-38. The temperature of a charging battery, which you obtain by a thermometer reading of the electrolyte, should not be much greater than the surrounding air temperature. If you don't have a thermometer, feel the battery case. If it is uncomfortably warm, it is too hot. Reduce the charging rate and the battery will cool. High temperatures shorten the life of the battery, so check the temperature regularly.

1-39. *Adjusting specific gravity.* Unless electrolyte is actually lost through spilling or leaking, or acid has been added, the full charge specific gravity of the electrolyte does not require adjusting during the life of the battery. Electrolyte decreases very little with age. Adjust it only if continued charging results in readings below 1.260 or above 1.310. Before adjusting the specific gravity, charge the battery at the normal rate until the specific gravity shows no further

rise with all cells gassing. Do not adjust the specific gravity of a cell if there is no gassing.

1-40. A low specific gravity reading means that you need to replace the electrolyte with a stronger solution. You need to adjust it upwards. To do this, withdraw some of the electrolyte from the cell and replace it immediately with electrolyte of a higher specific gravity. Continue the charge until all cells have been gassing for one hour, then check the specific gravity of the cells. If it does not check between 1.275 and 1.300, repeat the adjustment.

1-41. When the specific gravity reading is higher than 1.300, how do you adjust it down-

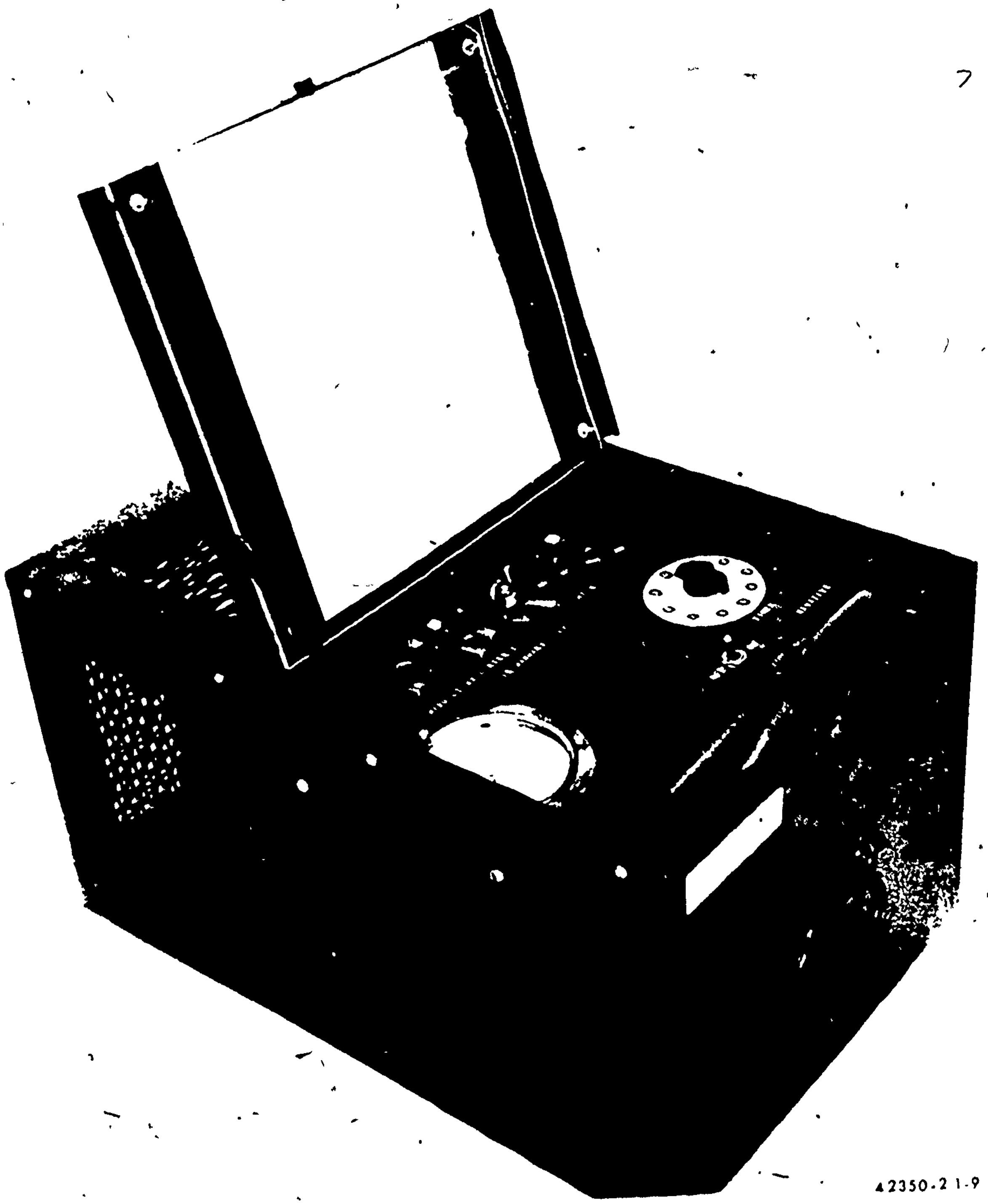


Figure 6. Capacity tester.

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ward? Common sense tells you to reverse the procedure for adjusting the electrolyte upwards, and you would be right. Withdraw some electrolyte and replace it with water. Charge the battery at a normal rate until all cells have been gassing for one hour. Check the specific gravity. If it is not between 1.275 and 1.300, repeat the adjustment.

1-42. **Capacity Testing.** The capacity test is a bench check to measure the terminal voltage of a lead-acid battery while it is under load, and to determine the battery's internal condition and state of wear. The results of the test determine whether the battery is worn out or has sufficient useful life to warrant its return to active service. Before performing the capacity test, fully charge the battery and then overcharge it for 2 hours. After checking to assure that the specific gravity of all cells is correct and within limits, allow the battery to stand for 12 hours.

1-43. The tester, as shown in figure 6, consists of two battery test leads which are bridged by an adjustable nichrome resistor. The tester also contains an ammeter, voltmeter, and a clock. After you have connected the load and voltmeter leads to the battery terminals, adjust the variable resistor to correspond to the capacity of the battery you are testing. As soon as you actuate the battery test switch on the tester, the battery delivers current and the recording clock records the time. You find the capacity testing information in TO 8D2-1-31. It is part of the same table you will use to determine the charging rates. Therefore, you must have a copy of the TO in the shop. Included in the table is the time, in minutes, that the battery is expected to deliver a certain amount of current (discharge rate). At the end of this time, the voltage must be equal to or above the voltage shown in the End Voltage column of the table. When testing a battery, you must carefully observe the voltmeter and the clock. When the clock reaches the time listed in the Discharge Time column of the table, the voltage should be equal to or above that listed in the End Voltage column of the table for the battery to have passed the test satisfactorily.

1-44. When you have tested the battery, and have found it suitable for further service, tag it and mark it "CAPACITY TEST OK." A record to indicate that a battery has been capacity tested and the date of the test is stamped on the battery case in a place where it will be plainly visible when the battery is installed in an aircraft. The capacity test is performed every 120 days and each new test date is recorded on the battery directly underneath markings or previous dates. After the battery has been marked, it is recharged and placed into service.

1-45. Batteries that do not pass the capacity test are no longer fit for service in an aircraft. These batteries are either condemned or painted bright yellow and stenciled with black letters "DO NOT INSTALL IN ANY AIRCRAFT—FOR GROUND USE ONLY." These batteries may then be used on testing devices, battery carts, or other equipment. They should not be used in ground power equipment, because ground power equipment requires the same high standards in batteries as do aircraft. A battery is used to start a piece of ground power equipment. If a battery isn't capable of supplying emergency power for an aircraft, it will never supply enough power to start a ground power unit.

1-46. **Maintenance.** You now know how to service, charge, and test a lead-acid battery. The easiest part of the whole section follows. What should you do with a defective or unserviceable battery? If you have carefully studied the preceding paragraphs, you know the answer. We discussed this in the capacity testing section. Batteries that fail the capacity test are generally condemned. You can be sure of one thing, if one cell is found defective in a lead-acid battery, the other cells are not far from being in the same condition. It is a waste of time and material trying to replace defective cells. True, some TO's give detailed instructions on how to replace cells and components, but they fail to say how many repairmen like yourself were successful in doing it.

1-47. As far as you are concerned, there is no repair made to the lead-acid battery. At this point, our discussion changes to the nickel-cadmium and silver-zinc batteries. They can be repaired by guys like you and me.

2. Nickel-Cadmium Batteries

2-1. The nickel-cadmium battery is the first of the two alkaline batteries that we will discuss; the other is the silver-zinc battery. The *alkaline* batteries receive their name from the materials that are used in the construction of the plates. Nickel-cadmium batteries have the following major advantages over the other commonly used batteries:

Subparagraph *a.* deleted.

b. They maintain a relatively steady voltage, even when they are being discharged at high currents.

c. They are not permanently damaged if they are overcharged, overdischarged, or charged in the wrong direction.

d. They can stand idle in any state of charge for an indefinite time.

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e. They retain their charge if they are stored in a charged condition for prolonged periods.

f. They are not damaged by freezing.

g. They are not subject to failure by vibration or severe jolting.

h. They do not usually give off corrosive fumes.

i. They are made up of individually replaceable cells.

Even with all of these advantages, the nickel-cadmium battery presents hazards to safety. Therefore, we will discuss safety first.

2-2. **Safety.** Many of the same hazards to safety that were discussed in the lead-acid battery section also apply when servicing nickel-cadmium batteries. In addition, the electrolyte used in nickel-cadmium batteries contains potassium hydroxide, which is a very strong alkaline. Like sulphuric acid, potassium hydroxide can cause serious burns if it contacts your skin. When handling this electrolyte, you should wear protective clothing, such as an alkaliproof apron, alkaliproof rubber gloves, face mask or goggles, and rubber boots. Sounds like a repeat of the lead-acid battery section, doesn't it?

2-3. The following procedures are recommended if you should accidentally splash some electrolyte on yourself:

(1) Internal. Take large quantities of water and a weak acid solution such as vinegar, lemon juice, orange juice, followed by either the white of an egg, olive oil, starch water, mineral oil, or melted butter. OBTAIN MEDICAL ATTENTION AT ONCE.

(2) External. To treat the skin, wash the affected area with large quantities of water. Neutralize with vinegar, lemon juice, or a 5 percent boric acid solution, and wash with water. If you get it in your eyes, wash with clear water or, using an eye cup, wash with a weak solution of boric acid or vinegar and water. Then repeat with clear water. OBTAIN MEDICAL ATTENTION AT ONCE.

2-4. As you see, there are many things you can use to neutralize potassium hydroxide. True, you may not have all of these items in your shop, but you should have the boric acid. As in the lead-acid battery shop, you should have running water available, such as a hose, deluge shower, and eye wash. The faster you can dilute any electrolyte splashed on you, the better off you are.

2-5. Nickel-cadmium battery shops will be mechanically ventilated to provide 3 to 4 air changes per hour. Adequate ventilation insures the removal of any hydrogen gas generated as a result of charging. Smoking and other ignition sources will be prohibited in the battery shop, because the hydrogen gas generated by nickel-cadmium batteries is explosive. Remember, you should remove all jewelry whenever you work around any electrical equipment, whether in the shop or on the flight line.

2-6. What do you think would happen if you accidently got some sulphuric acid electrolyte into a nickel-cadmium battery? This situation has occurred and accidents have resulted. If some sulphuric acid electrolyte gets into nickel-cadmium batteries and they are connected to a charging source, they can blow up. Why?

2-7. Without going into the chemical formulas, we will explain how this happens. When the acid is mixed with the alkaline, they tend to neutralize each other. Theoretically, if this happened we would end up with water. When the battery is connected to a charging source, the water acts as a short circuit in the battery, thereby resulting in a high current flow through the battery.

The high current flow causes excessive heat and the battery explodes. You can prevent accidents like this from happening by:

- Isolating alkaline batteries from lead-acid batteries.

Cartoon 3. Bang.

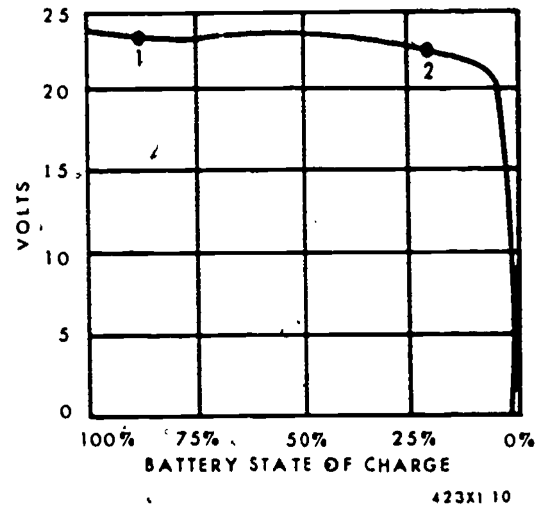

Figure 7. Typical discharge voltage curve.

- Not using the same tools on lead-acid batteries that you use on alkaline batteries.

Only you can prevent accidents from happening by knowing the hazards to safety that exist, and correcting them before you or someone else gets hurt. You must be safety conscious at all times.

2-8. **Shop Operation.** In the following paragraphs are common jobs that you will perform while working in a nickel-cadmium battery shop. Detailed information for servicing nickel-cadmium batteries and detailed shop procedures are in the applicable TO's. We discuss here general information that pertains to all nickel-cadmium batteries.

2-9. *Electrolyte.* The electrolyte is a 30 percent (by weight) solution of potassium hydroxide in distilled water. Generally, nickel-cadmium batteries contain the proper electrolyte when received. There may be times however, when you will be required to mix electrolyte. Remember the rule for mixing the electrolyte for lead-acid batteries. The same rule applies here. You pour the potassium hydroxide into the water. Heat is generated, so you must use the proper type container, such as was used with sulphuric acid. You cannot use any container that previously had sulphuric acid in it, because of acid contamination.

2-10. The proper level of the electrolyte in a nickel-cadmium battery is ⅛ inch above the top of the plates. During battery operation, some water may be lost due to normal gassing, venting, or overcharging. You can replace this loss with pure distilled water. If you add water to a battery, it must be discharged and recharged; this insures that the water mixes with the electrolyte in the cell.

2-11. *State of charge.* The state of charge of nickel-cadmium batteries cannot be determined by the battery voltage or by the specific gravity of the electrolyte. The normal-open-circuit voltage of a nickel-cadmium cell is 1.3 volts. To illustrate the fact that voltage does not show the state of charge, figure 7 shows a typical discharge voltage curve against the state of charge of the battery. A reading of about 24 volts means that the battery may be completely charged (point 1 on the curve) or almost completely discharged (point 2 on the curve). The state of charge cannot be determined by the specific gravity of the electrolyte, because the electrolyte is not changed by the chemical reaction that occurs in the batteries. The specific gravity is almost the same whether the batteries are charged or discharged.

2-12. A nickel-cadmium battery is at zero state of charge when it has been discharged to zero volts, and at a full charge when it has been charged by constant current. At any other time, the state of charge cannot be determined except by discharging and measuring the amount of discharge to the cutoff voltage. It cannot be determined by the specific gravity of the electrolyte since it does not change during battery charge or discharge.

2-13. *Servicing.* Before placing a nickel-cadmium battery on charge, you should check the case and cell for cracks, warpage, and electrolyte leakage. If you find a cracked or warped cell, replace it. If overcharging has occurred, gassing and bubbling of the electrolyte through the vents cause the formation of a white substance on top of the cells. This is nothing more than harmless

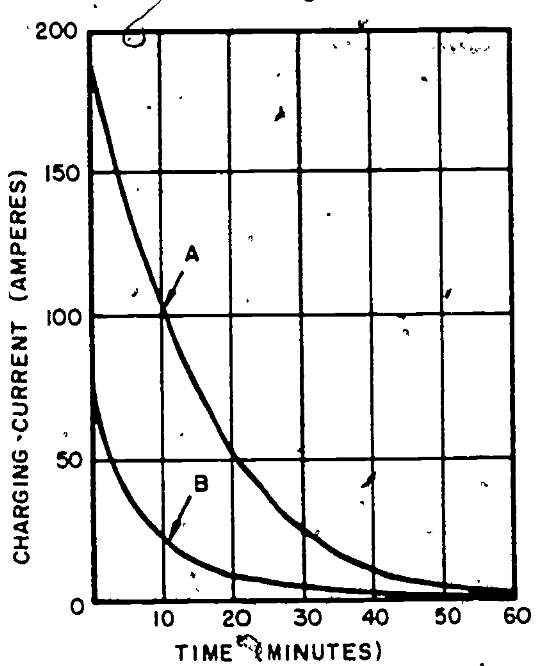

Figure 8. Charging curve.

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potassium carbonate, which you can easily remove with a stiff dry brush or by washing with water.

2-14. After you have cleaned the battery, inspect the terminals and cell connector bolts. Tighten them to the proper torque values listed in the applicable tech order. Do not subject the metal components of the nickel-cadmium battery to painting or the application of any anticorrosion compound.

2-15. **Constant-Current Charging.** Nickel-cadmium batteries are to be charged by the constant-current method only, and never while in parallel. Although this battery can be operated in any position, it must be charged in the upright position to prevent loss of electrolyte. Vent caps should be loose and in place during charge.

2-16. *Constant-potential charging.* Always connect the battery to be charged to an authorized battery-charger analyzer as specified in TO 8D2-3-1. Charge the battery as directed by the operating instructions outlined in the appropriate TO for the charger analyzer.

2-17. During charge, occasionally check the battery temperature. If the battery case begins to heat excessively (uncomfortable to touch), it may be necessary to add distilled water to the affected cells. Add water only until the electrolyte is visible above the baffle plate. Remember, you must always follow detailed procedures of the applicable TO.

Paragraph 2-18 deleted.

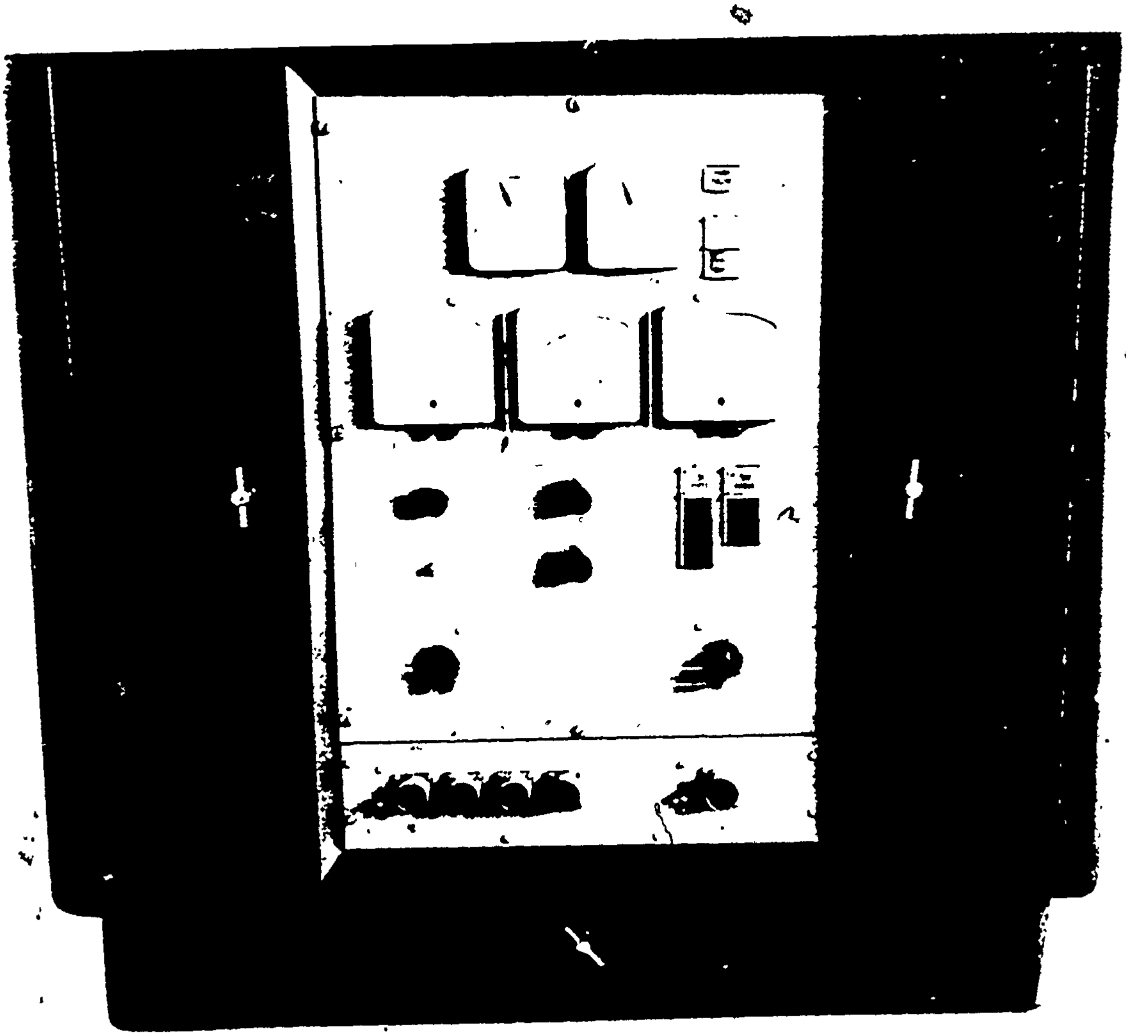

Figure 9. Charger/analyzer.

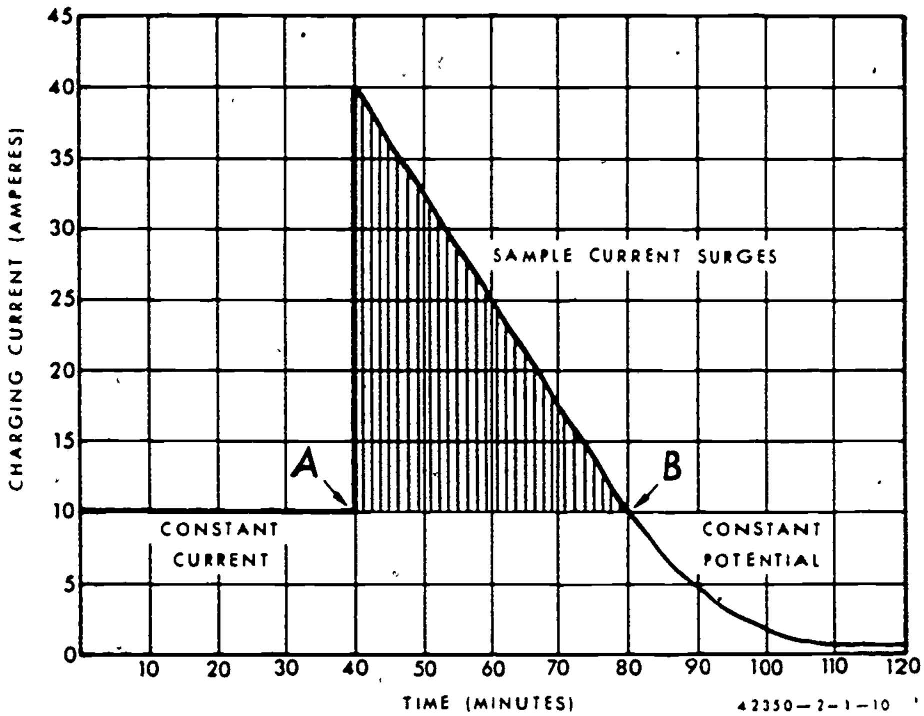

Figure 10. Charger/analyzer charging curve.

If you charge a nickel-cadmium battery by the constant-current method, you must consult the TO for the correct charging current and time.

2-19. *Charger/analyzer*. The charger/analyzer provides an automatic means of servicing the nickel-cadmium batteries. Figure 9 shows just one of many different types used by the Air Force. The front control panel of the unit contains the selector switches for the types of batteries it can service. It also contains voltmeters, ammeters, timers, and connections for the batteries to be serviced. Inside the cabinet is the secret of operation. This is where the transformer-rectifiers and the voltage and current-control relays are located. Normally, you do not perform any maintenance on this unit, but if a malfunction does occur, refer to the applicable TO for repair procedures. The unit shown serves three functions: charger, discharger, and analyzer. We will discuss each section individually.

2-20. *a*. Charger section. The charger section uses both the constant-current and constant-potential methods of charging. Just how is this accomplished? During the initial charge the current entering the battery is limited to a constant current. This is accomplished by the use of timers and current control relays. After a predetermined time an automatic and periodic sampling of the charging current is taken. When the charging current drops to a predetermined value, the charger reverts to the constant-potential method of charging. You can see this by looking at the charger/analyzer charging curve that is shown in figure 10. For example, we will use a constant current of approximately 10 amps to start. After a predetermined period of time, at point A on the curve, a 2-second sample of the charging current is taken. This is shown by the current surge lines. Actually what happens is that the current limiting control relays drop out and the charger reverts to the constant-potential method for 2 seconds. Remember, when batteries are charged by the constant-potential method, the amount of charging current is regulated by the state of charge of the battery. Therefore, if the battery is not charged, there is a sudden high current draw, but only for 2 seconds. Relays in the unit sense the high current draw and the unit reverts back to the constant-current method of charging. As the battery accepts a charge, the high current draw decreases, until we reach point B on the curve. At this point, the unit automatically reverts to a constant potential of 28.5 volts and continues to charge until the battery reaches its full rate of charge. The com-

plete charging cycle takes approximately 2 hours. The charger/analyzer can charge up to four batteries at one time.

2-21. *b.* Discharger section. The discharger section serves almost the same function as the capacity test discussed in the lead-acid battery section. It places the nickel-cadmium battery under a predetermined electrical load for a set period of time to measure its terminal voltage. After you have connected a battery to the discharger section and positioned the correct switches, the test is performed automatically. If the battery voltage does not drop below 19 volts within the 2-hour limit, a "DISCHARGE ACCEPT" lamp illuminates and further discharge stops. If the voltage drops below 19 volts before the 2-hour limit is up, discharge stops and a "DISCHARGE FAIL" lamp illuminates. If a battery fails the discharge test, each cell must be checked with a voltmeter to determine the defective cells. The discharger section can check only one battery at a time. However, it can be used while batteries are connected to the charger section. After a battery has been tested it must be recharged.

2-22. *c.* Analyzer section. When you connect a battery to the analyzer section, it goes through the complete cycle of charging, discharge testing, and recharging automatically. The complete operation takes 6 hours. During this time you cannot use the other sections of the unit, as they are now controlled by the analyzer section control switches. If at any time a battery fails to meet the requirements of any one cycle, the unit stops and a warning light illuminates to indicate which cycle failed, such as "CHARGE FAIL" or "DISCHARGE FAIL". When a battery completes all cycles satisfactorily, a "BATTERY GO" light illuminates and the battery is ready to be placed into service. If a battery fails to meet the requirements, you must determine the malfunction, which is generally defective cells.

2-23. **Maintenance.** Do you know how to use a torque wrench? If not, now is the time to learn. You can't perform any repair work on the nickel-cadmium battery without using a torque wrench. Even the preservicing, before placing the battery on charge, requires that you check the torque for the cell connector bolts. You will find the torque values in the applicable TO. Why torque the bolts? It goes all the way back to the fundamentals you learned about voltage, current, and resistance. A loose cell connector bolt causes high resistance and, as you know, high resistance causes low current flow. Therefore, the battery would not put out its rated current and would not accept a charge. This is why it is important that you torque all bolts properly.

2-24. As we said earlier in this section, the nickel-cadmium battery is composed of replaceable cells. When one cell goes bad, you replace just that cell. Before you attempt to replace a cell, you must completely discharge the battery. To completely discharge the battery, connect it to a load bank until the cell voltage drops to .9 of a volt. Then place a jumper wire across each cell. The jumper wire can be just a few turns of heavy safety wire. After you install the jumper wires, allow the battery to set for 8 hours. As the battery discharges, it produces heat which expands the cells. Therefore, you must allow the battery to cool before you try to remove any cells. Cell removal is quite easy if you follow the instruction outlined in the TO. Some batteries require that you remove a key cell before you can remove any other cells; this varies with each type of battery. So, make it easy for yourself and check the TO.

2-25. When installing a new cell, be sure that it is completely discharged. The easy way to get a new cell to slide into place is to put a thin coat of vaseline on the sides of the cell. After you have the cell installed, remember that you must torque the connecting bolts.

2-26. The largest part of the repair work that you will be doing is replacing defective components. There is no repair made to a defective cell; it is condemned the same as a lead-acid battery. This is also true in the maintenance and repair of the silver-zinc battery which we will now discuss.

3. Silver-Zinc Batteries

3-1. The silver-zinc battery has many of the same advantages as the nickel-cadmium battery. We must also say that there are a few exceptions or disadvantages as compared to the nickel-cadmium or even the lead-acid. The greatest advantages that the silver-zinc battery has over the other two are its size and its capacity ratio. The silver-zinc is approximately half the size of the other batteries but it has an ampere-hour capacity rating of double that of the other batteries.

3-2. The use of the silver-zinc battery is very limited. It was designed for use in aircraft as an emergency source of direct current and not for the operation of electrical equipment while the aircraft is on the ground. The battery is very sensitive to excess voltage and high current. Because of this, the aircraft's dc system must be accurately adjusted to limit the voltage at the battery terminal to 28 volts maximum. Along the same line, the battery must be checked for its state of charge before the aircraft engines are

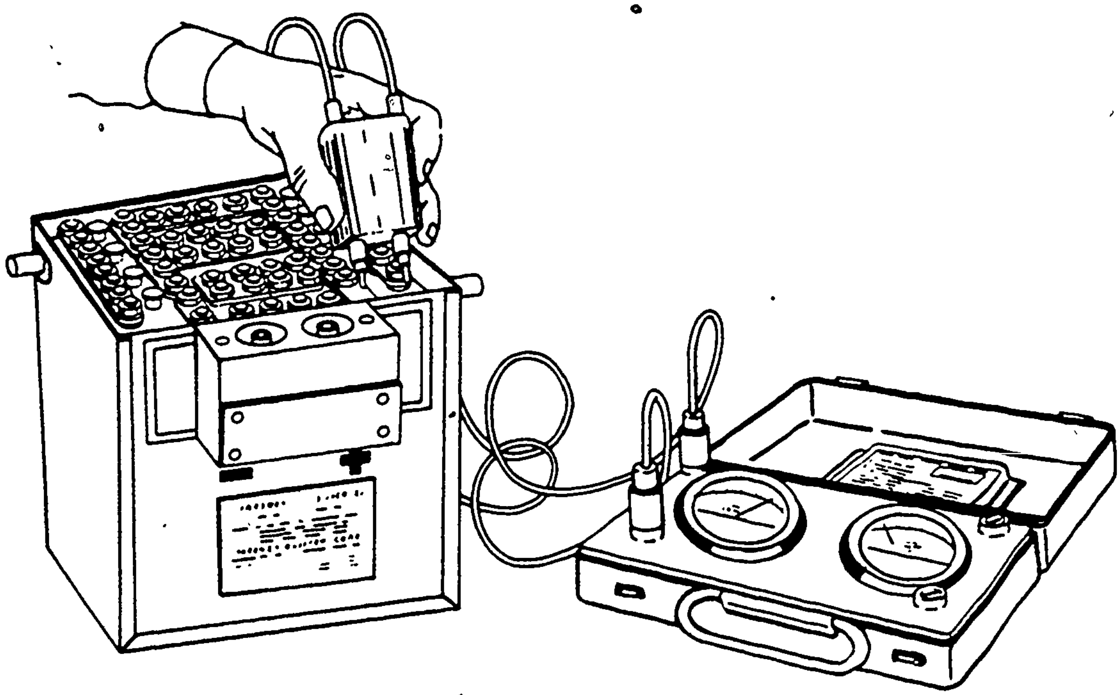

Figure 11. Testing battery cell voltage.

started. If the state of charge is low and the battery is connected to the aircraft buses, the high current trying to charge the battery will be just as destructive as high voltage. For these same reasons, the battery should never be connected to the aircraft bus if external power is applied.

3-3. **Safety.** The hazards to safety that exist with the silver-zinc battery are the same as those that were discussed in the nickel-cadmium section. Your knowledge of these hazards is the only way that you can prevent accidents from happening.

3-4. The silver-zinc battery, like the nickel-cadmium battery, uses potassium hydroxide in the electrolyte. Therefore, the same type protective clothing and neutralizing agents can be used. Remember, the greatest hazard to safety is acid contamination. Be aware of it at all times; get careless just once, and you may not have a second chance.

3-5. **Shop Operation.** The silver-zinc battery shop should look more like a laboratory than a battery shop. It should be air-conditioned because controlled temperature is necessary for proper battery servicing. Cleanliness is a must. As with the nickel-cadmium shop, the silver-zinc shop must be totally isolated from the lead-acid batteries to prevent acid contamination. You can find detailed information for servicing batteries and detailed shop procedures in the applicable TO. We will discuss here some general jobs and information that pertains to all silver-zinc batteries.

3-6. *Electrolyte.* The electrolyte for the silver-zinc battery comes premixed with each new battery you receive. This eliminates mixing electrolyte. You still must use caution while handling the electrolyte though, because it contains potassium hydroxide.

3-7. Unlike the lead-acid and the nickel-cadmium batteries which are filled with electrolyte to a specifed level, each cell of the silver-zinc battery is filled with a measured amount of electrolyte. Once a cell has been filled it does not require the addition of water or electrolyte at any time during its use.

3-8. Another exception is that after you have serviced the silver-zinc battery with electrolyte, you must allow it to stand for 72 hours before taking any further action. This is known as the soaking period. As you remember, lead-acid and nickel-cadmium batteries could be placed on charge immediately after being serviced with electrolyte.

3-9. *State of charge.* So far, we have discussed two different batteries, the lead-acid and nickel-cadmium, each having a different way to determine the state of charge. Do you remember what they are? You determine the state of charge of the lead-acid by the specific gravity of the

electrolyte, and the nickel-cadmium by the amount of current the battery draws when connected to a constant-potential charging bus. Now we have a third way to determine the state of charge.

3-10. The state of charge of the silver-zinc battery is determined by measuring the open-circuit voltage across each cell. You do this by using the battery tester, RAC777-1, as shown in figure 11, or by using a voltmeter which reads accurately to .01 of a volt. A voltage reading of 1.82 volts or higher for each cell indicates that the battery is 70 to 100 percent of its rated capacity. A voltage reading below 1.82 volts is less than an acceptable state of charge. This requires that the battery be serviced.

3-11. *Servicing.* You must service and charge the silver-zinc battery in strict accordance with the manufacturer's instructions and technical orders. You cannot expect a normal service life unless they are followed carefully. At the present time, the normal service life of a silver-zinc battery is approximately 15 months. In fact, the battery must not be allowed to exceed 15 months of age from activation date. This time begins when the battery is first serviced with electrolyte and can end prematurely with improper care and servicing. The proper care and servicing is part of your job.

3-12. Before you place a new or used battery on charge, you should inspect the top of the battery for corrosion and damaged cells. Remove any corrosion by wiping clean with a damp cloth. When you have the battery clean, check the tightness of the nuts on the intercell connectors. If any are found loose, tighten them; but before you tighten them, be sure to check the TO. With the TO as a guide, you must torque all nuts with the torque wrench. After you have cleaned the battery and checked all nuts for the proper torque, you are now ready to charge the battery.

3-13. **Charging Methods.** This is another area where the silver-zinc battery is quite different from the lead-acid or nickel-cadmium batteries. The silver-zinc battery goes through a charging process which is called formation charging. This is a process of charging and discharging the silver-zinc battery in a controlled sequence to condition the internal elements of the battery. This conditioning enables it to deliver its maximum rated capacity.

3-14. Just what does this mean to you? The key words are "to condition." Look at it this way. For some reason or other, you are required to do 45 pushups. You know you can't do this many pushups at one time without practice, but you can condition yourself to be able to. To do this, today do 5 pushups, and each day thereafter do 5 more than the day before. On the 9th day you would be able to do the required 45 pushups This would be your rated capacity. We could apply this same idea to the conditioning of a silver-zinc battery. A predetermined amount of current or charge is placed in the battery. After we put the charge into the battery, we take it back out or discharge the battery. Then we start all over again and this time we increase the charge. This process continues until we reach the rated capacity of the battery.

3-15. It may sound like an easy job to charge a silver-zinc battery. Don't believe it. All the time that you are servicing the battery, you must closely check and record the charging current, battery voltage, and battery temperature.

3-16. A special form AFTO Form 71, *Shop Processing Formation Worksheet,* is provided for the purpose of recording all actions taken during the servicing, formation charging, and service life of the battery. This form is very important to you, especially when someone else is working in the battery shop with you. By reviewing the entries on the form, you can determine what actions have been taken and what remains to be done. Including the soaking period, and depending upon the number of formation charging cycles you have to perform to reach the rated capacity, it can take up to 12 days to service a silver-zinc battery. You can find detailed instructions for the completion of the form in the TO on silver-zinc batteries. Like the lead-acid and nickel-cadmium batteries, the silver-zinc batteries can be charged by both the constant-current and constant-potential methods.

3-17. *Constant current.* The constant-current method is the recommended way of charging the silver-zinc battery. The silver-zinc battery charger, shown in figure 12, provides the best charging source. It incorporates all of the voltmeters and ammeters that are required to monitor the charging. This charger has a built-in load bank used for discharging the battery. There are many different types of chargers in use today, so consult the applicable TO for the correct operation of the one you use.

3-18. *Constant potential.* In an emergency, you may use a constant-potential source. The input voltage must be closely monitored so as not to exceed 28 volts, and the current must be controlled to limit the initial current surge to 50 amperes or less. A higher current will damage the cells.

3-19. **Maintenance.** As with the nickel-cadmium battery, maintenance of the silver-zinc bat-

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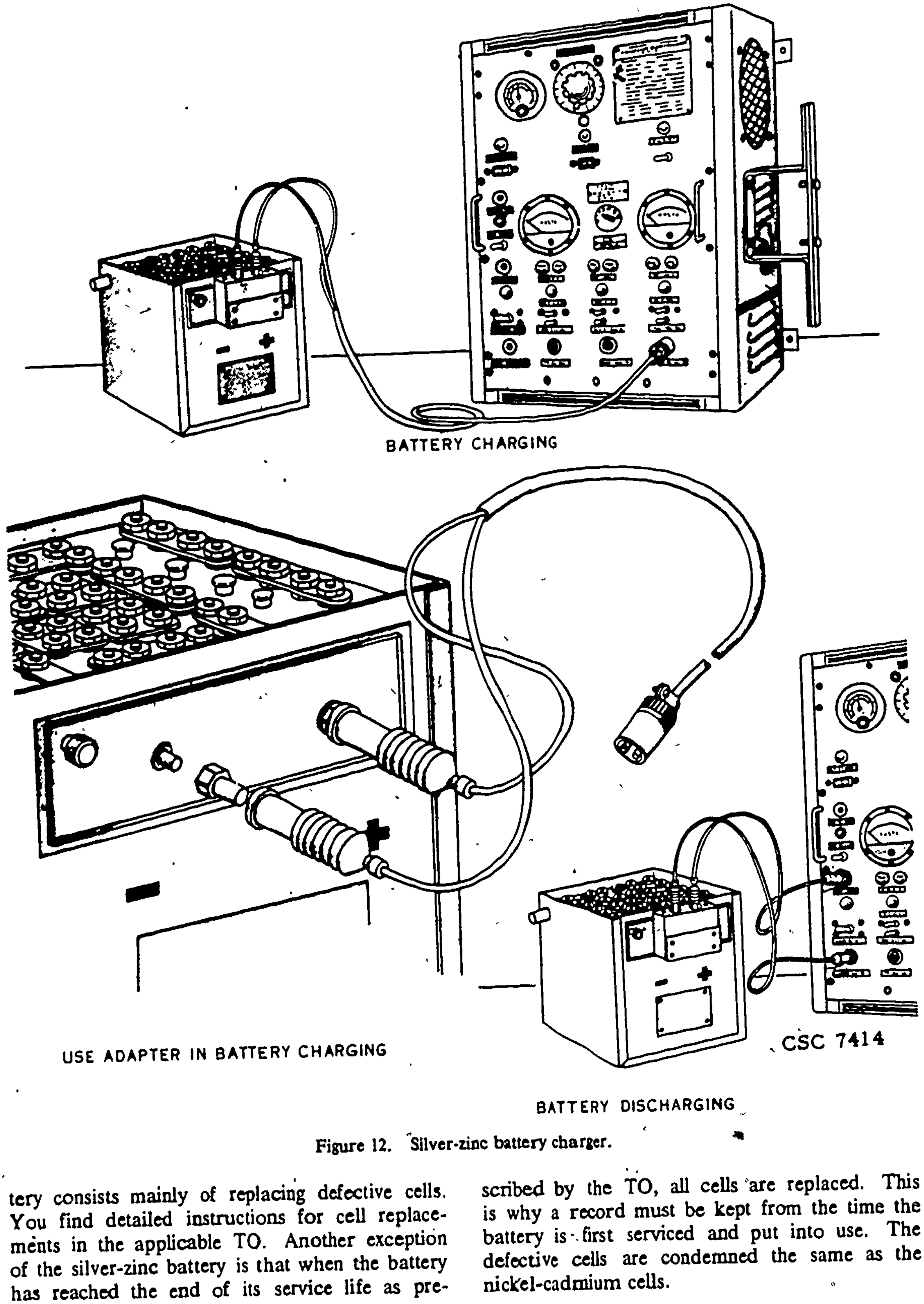

Figure 12. Silver-zinc battery charger.

tery consists mainly of replacing defective cells. You find detailed instructions for cell replacements in the applicable TO. Another exception of the silver-zinc battery is that when the battery has reached the end of its service life as prescribed by the TO, all cells are replaced. This is why a record must be kept from the time the battery is first serviced and put into use. The defective cells are condemned the same as the nickel-cadmium cells.

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Power Systems Test Equipment

AIRCRAFT must be kept at their highest efficiency at all times. Since most of the mission equipment is electrically operated, the power system must be kept in perfect operating condition. In addition to the mission equipment, many of the aircraft control systems also depend on the electrical systems.

2. In order for the electrician to keep the power system at its highest peak of efficiency, special test equipment had to be provided. The requirement for this special test equipment has been brought about by the complexity of today's systems.

3. In the old days, a voltmeter or an ohmmeter would do the job. Now, you must use test equipment that duplicates the operating conditions found in the power system to provide the means of testing system components. You must be responsible for the operation and maintenance of the test equipment. In this chapter, we will discuss the more common types of test equipment identified with power system testing.

4. In this chapter, we will divide power systems test equipment into two areas, dc and ac. During the discussion of the dc power systems test equipment, two items will be covered, the A–2 generator test stand with load bank and the T–31 tester. The ac power systems test equipment coverage includes testing and loading. The testers are T–35, T–170, and MC–2 test stand; the loader is an A–1 load bank. Each of the above stated items are covered with respect to construction and operation. Later in this course, under aircraft power systems, the test equipment covered in this chapter will be used to determine system malfunctions.

4. DC Test Equipment

4-1. As the name implies, the equipment to be tested operates in a dc system. To control system operation, in order to determine discrepancies, test equipment has been built to simulate aircraft operation. This test equipment is the subject in this section.

4-2. **DC Generator Test Stand.** You have no doubt already seen and realized the importance of the generator test stand in daily shop operation. Figure 13 is a picture of a typical A–2 test stand. Don't be alarmed if it isn't the same as the one that you have in your shop. There are many different versions still in service. However, they all perform the same as the one that you have in your shop. They all perform the same two basic functions: (1) they turn the generator at various speeds and (2) they provide a means of applying a load to the generator under test.

4-3. *Description.* What are some of the capabilities of the generator test stand? This test stand simulates the operational service conditions for testing 30-volt dc generators with ratings up to 600 amperes. It is usually referred to as a varidrive since it provides a means of regulating generator speed. It also provides a means of applying loads to the generator under test.

4-4. On top of the test stand there is a resistive load bank. The switches (item C, fig. 13), located on the front panel, control the resistive load bank. The load bank is used to provide a load for the generator under test. When a switch is placed in the ON position, it connects a bank of resistors in parallel with those already in the circuit.

4-5. This load bank gives us an opportunity to apply Ohm's law to the series and parallel circuits involved. The generator output is applied between the "28 VDC" and the "COMMON" terminals. What load would be applied to the generator if the generator voltage is set at 28.5 volts and a 10-amp switch is closed? Each 10-amp switch connects a 2.85-ohm resistance in parallel with generator output. Current equals source voltage divided by circuit resistance.

$$I = \frac{E}{R}$$

$$I = \frac{28.5 \text{ volts}}{2.85 \text{ ohms}}$$

$$I = 10 \text{ amps}$$

4-6. Now, what would happen to the current if the generator voltage is set at 30 volts and

a 10-amp switch is closed? Figure it out and you'll come out with 10.5 amps. Also, if the generator voltage is less than 28.5 volts, we have a current flow of less than 10 amps. From this discussion we have determined that the load switches apply only to an approximate load. Actual load is determined by generator voltage. However, the indicated loads are close enough for daily operation of the test stand.

4-7. The 20-, 40-, and 100-amp switches involve parallel circuits. When any of these switches are closed, the total current flows through the switch and then divides through each leg of a parallel branch. There are a number of ways to determine the current flow through these parallel branches. Let's discuss a 40-amp branch (four 2.85 ohm resistors in parallel) using two different approaches. We find total resistance by using the formula:

$$RT = \frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3} + \frac{1}{R4}$$

Because all resistors are of the same value, we merely divide the value of one resistor by the number of resistors in the string. In this case, 4. Current flow is then found by dividing source

$$\frac{2.85}{4} = 0.7125 \text{ ohms}$$

voltage by total resistance.

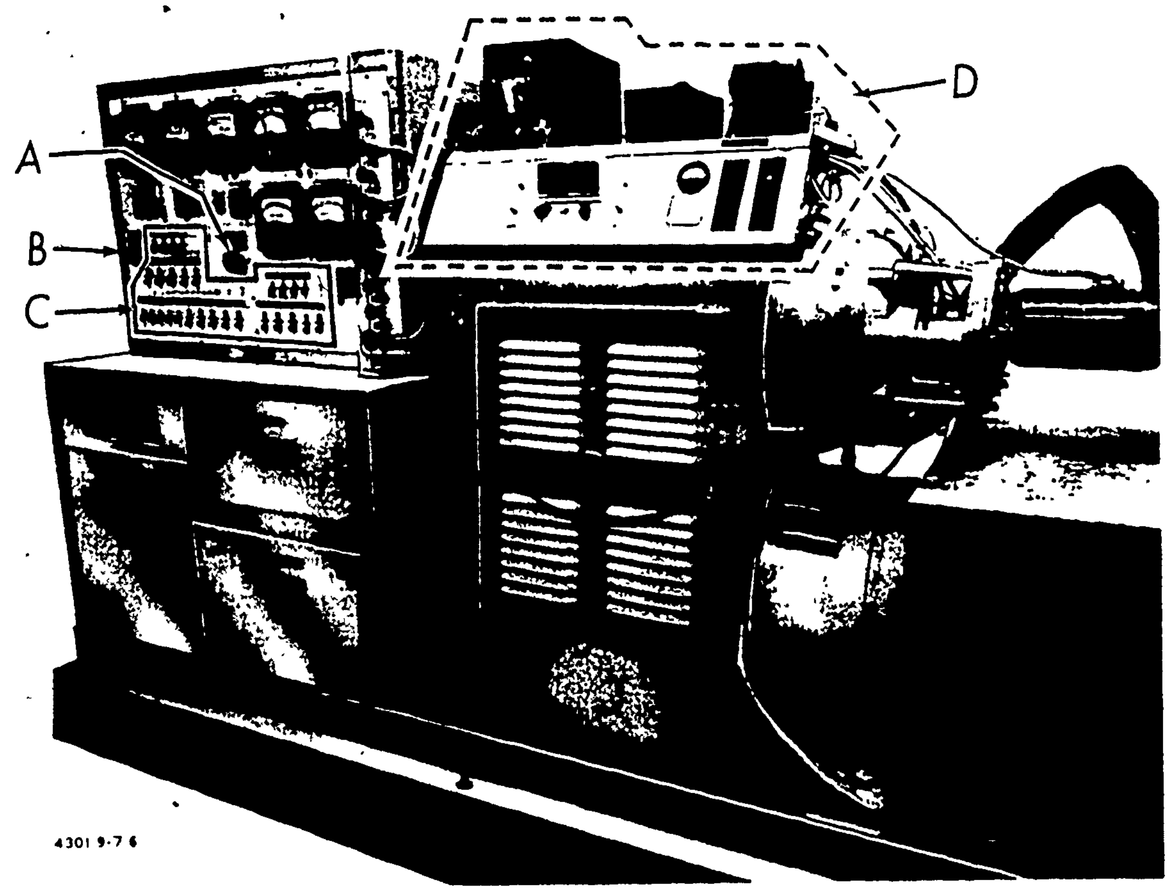
$$I = \frac{E}{R}$$

$$I = 40 \text{ amps}$$

4-8. Another method of determining current flow in a parallel circuit is to determine current through each branch. Then add these branch currents to find total current. We have already solved for current flow through a series 2.85-ohms resistor and found it to be 10 amps. In this case of four parallel 2.85-ohm resistors, we have a total current of

$$10 + 10 + 10 + 10 = 40 \text{ amps}$$

Again the amount of load provided by each switch is approximately equal to the ampere desig-



A. VARIABLE LOAD RHEOSTAT
B. GENERATOR FIELD CONTROL RHEOSTAT
C. LOAD BANK SWITCHES
D. TEST STAND MODIFICATION

Figure 13. A-2 generator test stand.

nation indicated on the panel face. As we proved before, actual current is determined by generator voltage.

4-9. A variable resistor (item A, fig. 13) is provided for a variable control of generator current output from 0 to 25 amperes. This resistor adds a limited amount of resistance in parallel with the bank resistors.

4-10. To control the generator output voltage, a variable 0-to 10-ampere generator field control (item B, fig. 13) is provided. This rheostat allows more resistance to be placed in series with the generator field, thereby controlling the generator output voltage.

4-11. There are various types of meters on the face of the panel. These meters indicate the various aspects of generator performance such as voltage, current, and speed of the generator. You should become completely familiar with each meter and all other controls before attempting to operate the test stand.

4-12. The basic generator test stand is unable to check all of the generator system components. But, with a little work on your part, you can greatly increase the capabilities of the test stand. All you have to do is to modify the stand to incorporate the wiring of the basic generator system. Now, let's expand some on this subject of modification.

4-13. *Modification.* The enclosed portion (D) of figure 13 is a modification that was performed by the local electric shop. You will probably recognize some of the components installed during the modification as being dc generator system components.

4-14. Where do you get permission to modify the generator test stand and why must it be modified? We'll take these questions one at a time. Normally you aren't allowed to modify anything without the proper authority. Furthermore, modifications should be limited to the external mounting of components which would not affect the basic test stand. In this way, you can also change the modifications to meet new needs.

4-15. Modifications should be performed only if it increases the versatility of the test stand. Since the test stand provides a means of turning the generator and applying loads, why not incorporate the other generator system components? The modified test stand would then enable you to test all generator system components. This would include testing and calibrating the voltage regulator, field control relay, RCR, overvoltage relay, and of course, the generator. Since the generator can be driven at various speeds and various loads applied, a thorough check of component operation can be made.

4-16. As you have probably guessed, the modification is a mockup of the aircraft generator system. Most dc generator systems are basically the same. Therefore, one system can probably take care of all your needs. The components should be mounted in such a manner that they can be replaced easily by the component under test. All wiring and connections should be installed with the same care and precautions used in aircraft wire maintenance. A neat and systematic layout of the components produces a piece of test equipment of which you will be justly proud.

4-17. *Servicing.* Maintenance of the generator test stand is the responsibility of the electric shop personnel. Whenever you are placed in a position that requires you to operate the stand, you should also be aware of the maintenance requirements. The test stand TO covers the maintenance of the stand as well as the operating procedures. So, after you finish reading the section on operation, continue on and read the maintenance requirements.

4-18. The importance of preventive maintenance of the stand cannot be overstressed. It must be properly inspected and serviced just like any other piece of mechanical equipment. It pays to properly grease and lubricate the stand at the prescribed intervals. You know—we might even consider this action as an insurance policy. It's much easier to spend a little time servicing the test stand than it is to explain to the chief-of-maintenance why you had a bearing failure. This is especially true if it occurred due to a lack of lubrication and happened at some crucial time. So always remember to check the applicable TO and keep the test stand properly serviced.

4-19. *Safety.* Become familiar with the TO that applies to your equipment. Get checked out on the operation of the test stand. Then become safety conscious, and always remain so. Follow these three steps before you start working on or operating the test stand.

4-20. **T-31 Tester.** The model T-31 dc system tester (fig. 14) is designed to provide a fast and uniform method of testing and adjusting dc generator control panels. With special wire harnesses, it can be adapted to test other dc system components. This tester is powered by 115 volts ac and does not incorporate the use of a dc generator. You may conduct the bench check of a control panel without access to the internal components since all indications of proper-relay-functioning are visible on the tester by means of lamps and meters. A 12-position selector switch on the panel face atuomatically connects the proper voltmeter range, the proper indicator

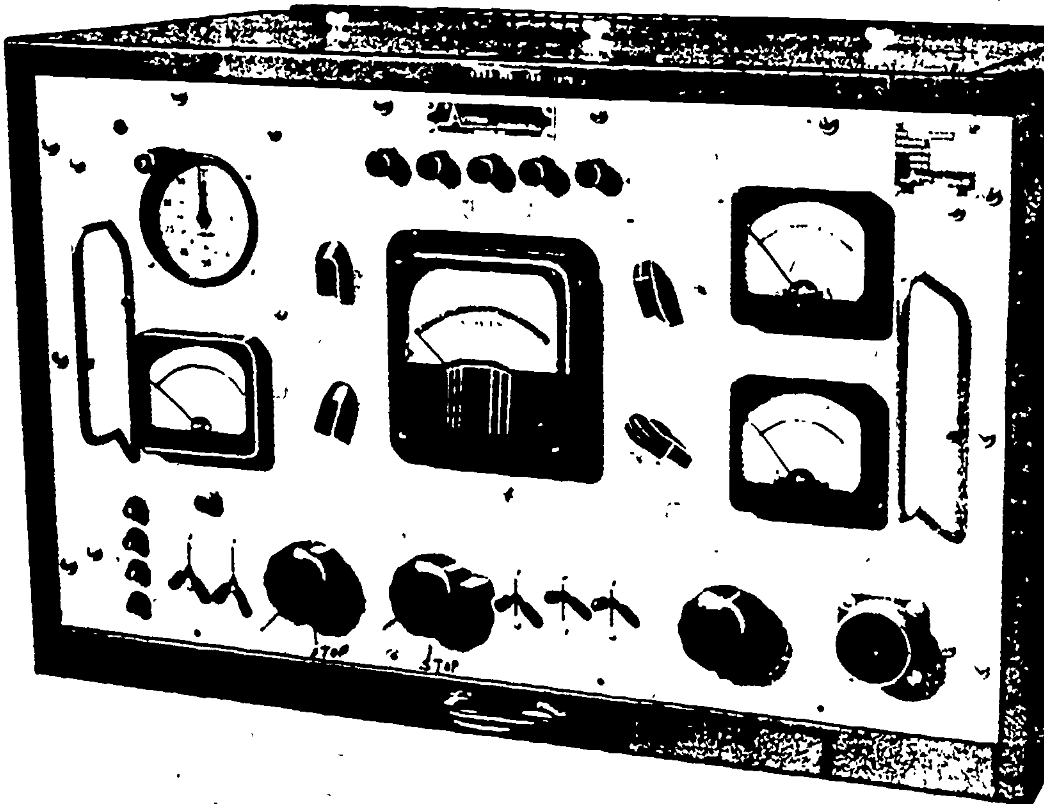


Figure 14. T–31 tester.

lamp, and correct electrical power to the various circuits in each component.

4-21. Dc control panels, as previously mentioned, are getting rather scarce since most of the newer aircraft are turning toward ac power. However, there are still many uses for this tester in shop repair work. Various test harnesses can be made up so that you can use the timer or any of the other meters on the front panel. This provides you with a means of testing many other system components.

4-22. If your shop has a T–31 tester, we suggest that you get the applicable TO and read it. Here you find the step-by-step operating procedure and a wiring diagram for the tester. The diagram will be helpful when you want to adapt the tester to uses other than those for which it was designed. Maintenance on the tester is limited to the repair of electrical circuit malfunctions. These will be few and far between if the tester is operated as prescribed in the TO. Calibration of the meters on the T–31 is performed by PMEL.

5. AC Test Equipment

5-1. Formerly the dc power systems were the prime electrical system on aircraft, but today the new aircraft are ac powered. As pointed out earlier, the vast majority of the systems on an aircraft are in some way dependent upon electrical power. The more systems dependent upon electricity, the more variable the levels of voltage will have to be. Ac is a good source of power that can be easily changed in potential. Since ac is more prominent than dc now, it is logical to devote more space to the testers of ac power equipment. Another reason for more coverage is that ac power systems are more diverse in components and operation than are dc power systems. For these reasons, the rest of this chapter will cover ac power systems test equipment. The first piece of test equipment we will consider is the T–35 tester.

5-2. **The T–35 Tester.** The T–35 tester, or control panel test set is designed specifically as a general purpose test set for all control and protection panels not containing transistors. The voltohmmeter is used for troubleshooting, and the test set is used for operational performance. The test set tells you the status of each item in the control and protection panels. You can test the performance of your equipment with this tester by simulating various voltage or frequency conditions that may occur in flight. You are re-

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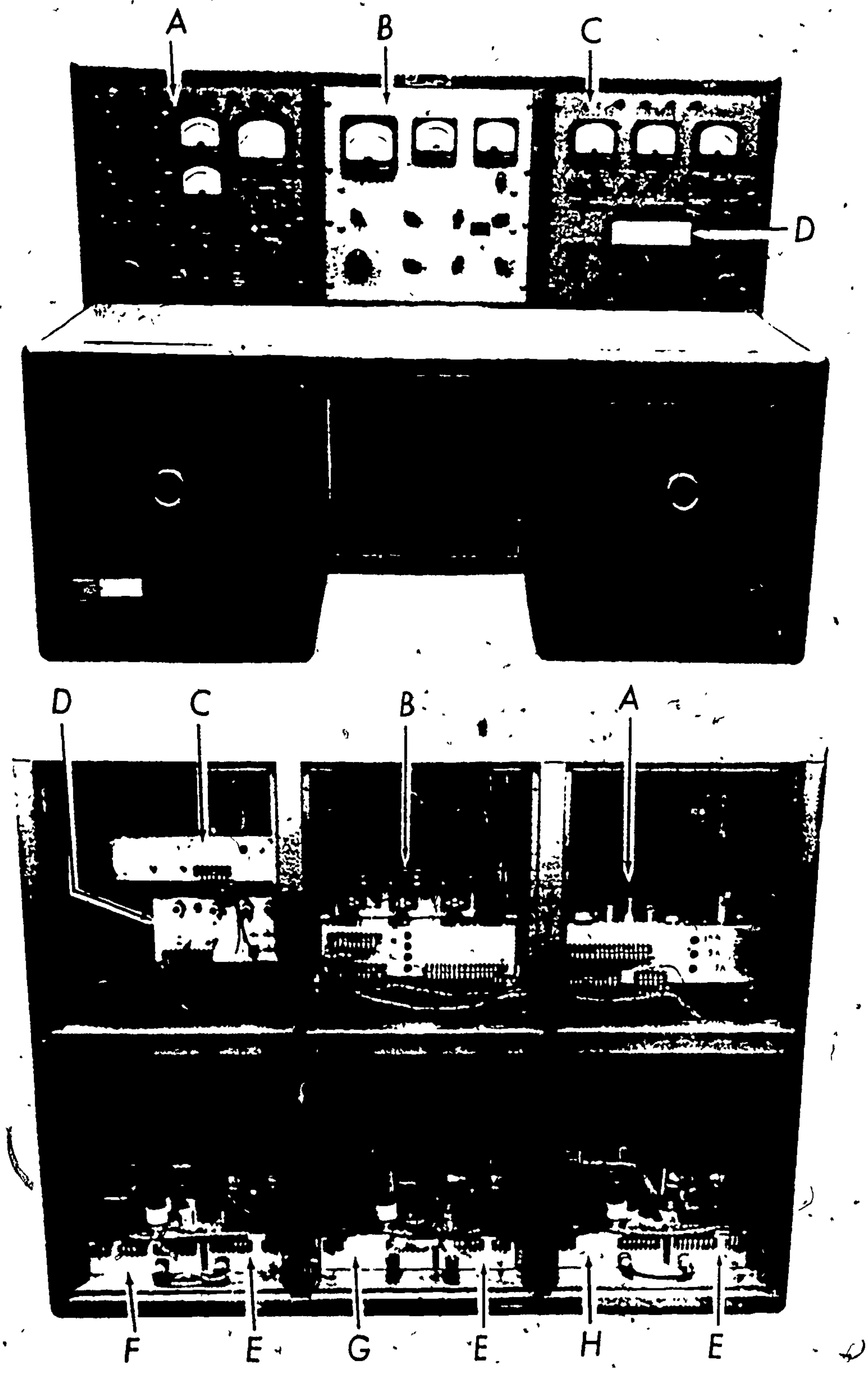

A. DC POWER METERING AND CONTROL UNIT
B. AC METERING AND CONTROL UNIT
C. METERING AND CONTROL UNIT FOR CONSTANT-SPEED DRIVE CONTROL
D. AC ELECTRONIC GENERATOR
E. POWER AMPLIFIERS
F. POWER SUPPLY (A PHASE)
G. POWER SUPPLY (B PHASE)
H. POWER SUPPLY (C PHASE)

Figure 15. T-35 tester.

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sponsible for operation and maintenance of this test equipment. The following discussion is designed to acquaint you with the various circuits and components within the test stand. The T–35 tester provides a fast and uniform method of testing and adjusting certain ac power generator system components. In order to test other ac power-generating components, special test leads are necessary. The components to be tested and adjusted, which will use all the test set circuits and meters, are the ac control panels, frequency and load controllers, autoparalleling controls, and underspeed controls.

5-3. **Components.** The T–35 test set consists of an ac electronic generator, power amplifier, amplifier power supplies, an ac metering and control unit, a dc power supply metering and control unit, and a metering and control unit for the constant-speed-drive controls (see fig. 15). These units are housed in a desk type console and are interconnected to provide a complete test set for checking certain makes and models of the generator and control panels and constant speed drive controls and their components. The components that make up the test stand are mounted on shelves in the back of the tester and are easily accessible through inspection doors.

5-4. *Ac electronic generator.* This unit furnishes three-phase, low-amplitude, low-distortion, sine wave voltages for the control and protection panels that are being tested. This generator produces the normal operational voltages for checking out the units in the control and protection panels. The frequency of the voltage may be manually adjusted over a range of from 310 to 440 Hertz (Hz, formerly cps) plus or minus 1 Hz, or over a range of from 390 to 410 Hz, plus or minus 0.1 Hz. This is done with the calibrated dial on the panel of the electronic generator unit (item D, front of fig. 15). A high-frequency, single-phase supply voltage also is furnished by this unit to simulate the signal generated by the underspeed system employing a magnetic pickup used on some constant-speed drive units. This section is calibrated in terms of the speed necessary to turn the gear in the drive unit to produce a signal of the same frequency.

5-5. *Power amplifiers.* There are three power amplifiers (item E, rear of fig. 15), one for each phase, to increase the low-amplitude, low-power voltage from the generator to a 115-volt, line-to-neutral voltage at outputs from 0 volt-amperes to 90 volt-amperes. The amplifiers incorporate the necessary circuits that provide very low source impedance, and regulation to insure constant voltage outputs with load or line voltage variations. Phase A, B, and C power amplifiers each employ a power supply, the function of which is explained later in the operation section.

5-6. *Amplifier power supplies.* The three amplifier power supplies (items F, G, H, rear view, fig. 15) furnish the required voltages for the filament and the various anode and bias voltages that are required for the operation of the electronic generator and power amplifiers. They consist of transformer-rectifier tube circuits with filter networks.

5-7. *Ac metering and control unit.* This unit contains the necessary controls and metering and switching equipment for making tests of the ac operated circuits of control panels and controls (item B, fig. 15). Three-phase voltages, balanced in amplitude and manually adjusted from 0 to 150 volts, are provided for making tests. Also, an unbalanced three-phase supply, with any selected phase having a variable voltage while the other two are held at 115 volts, is provided.

5-8. *Dc power supply metering and control unit.* This unit contains a fixed voltage dc power supply as well as an adjustable voltage dc power supply to provide the necessary dc power to operate the control panel components and to provide indications of operation of the various components, (item A, fig. 15).

5-9. *Metering and control unit for constant-speed drive controls.* The necessary power metering and switching required for checking the drive controls are incorporated in this unit (item C, fig. 15). Also a separate receptacle for making tests on the drive controls is provided. All of the necessary test leads for connecting the units being tested to the test set are furnished with the tester and are found in the drawers of the console.

5-10. **Operation.** The T-35 tester is used for control panels rated at 115/200 volts, 400 Hz, single or three-phase. The input required for the set is 115 volts, 60 Hz, single-phase power with a maximum load of ~~10~~ amperes. The maximum output of the 400-Hz ac generator is [illegible] volt-amperes per phase. The three-phase voltage is adjustable from 0 to 150 volts. Single-phase voltage, manually adjustable from 0 to 300 volts, is also provided. Fixed dc power is available at 26 volts nominal. A variable dc voltage is available and is adjustable from 0 to 60 volts. The test set subassemblies are connected together with harness assemblies. The relationships of the subassemblies are shown in the block diagram of figure 16.

5-11. *Power supply, phase A.* This power supply provides the necessary plate, bias, and tube heater power to the ac generator. A trans-

former and a 5Y3 rectifier tube with a filter network supply a positive 280 volts dc. The highest voltage secondary of this transformer is also connected to a 6X4 rectifier tube which supplies a negative voltage through a filter network to an OB2 regulating tube. This voltage regulating tube provides a negative 108 volts dc, which is the reference voltage for the output voltage regulator of the amplifier.

5-12. The heater power at 6.3 volts ac for the amplifier is furnished by the secondary of another transformer. The highest voltage secondary of this transformer is connected to a 5Y3 rectifier tube with the rectified output filtered. This output, 300 volts dc provides plate power for the low-level stages of the amplifier. Through a voltage divider network, a negative grid bias of 50 volts dc is obtained for the output stage of the amplifier. Another transformer has its high-voltage secondary connected to two 5R4 rectifier tubes. These tubes are connected in parallel. The output of these two tubes provides 750 volts dc to the plate of the output stage of the phase A amplifier.

5-13. *Power supply, phase B and C.* These power supplies furnish the plate, bias, and heater power for the amplifier for the phases B and C amplifiers (see fig. 16). The operation of these power supplies is identical to the power supply for phase A, which we discussed previously. There is a −108 volts dc output used as a reference for the output regulation of the amplifier, +6.3 volts ac output for heater power to the amplifier tubes, +300 volts dc for the plates of the low-level stages of the amplifier, −50 volts dc for the grid bias of the power-output stage of the amplifier, and a +750 volts dc for the plate supply to the power-output tubes of the amplifier.

5-14. *Power amplifiers.* The electronic amplifiers are used to amplify the low-level, three-phase voltages produced by the ac generator. These three phases A, B, and C amplifiers, are identical in construction and operation. They increase the power to each line-to-neutral voltage; and each supplies a voltage, adjustable over a range of from 95 to 130 volts ac, delivering approximately 90 volts-amperes at 115 volts. The output voltage is independent of load variations and does not exceed ±0.5 volt from no load to full load. Each amplifier is connected to a power supply which provides the necessary plate, bias, and tube heater power. An input signal from the ac generator is applied to the grid of a triode tube. The signal is amplified and coupled to the appropriate stages consecutively. A degenerative feedback circuit stabilizes the gain of the amplifier, and reduces distortion of the output signal.

5-15. *Ac electronic generator.* This generator is a stable electronic oscillator with a balanced

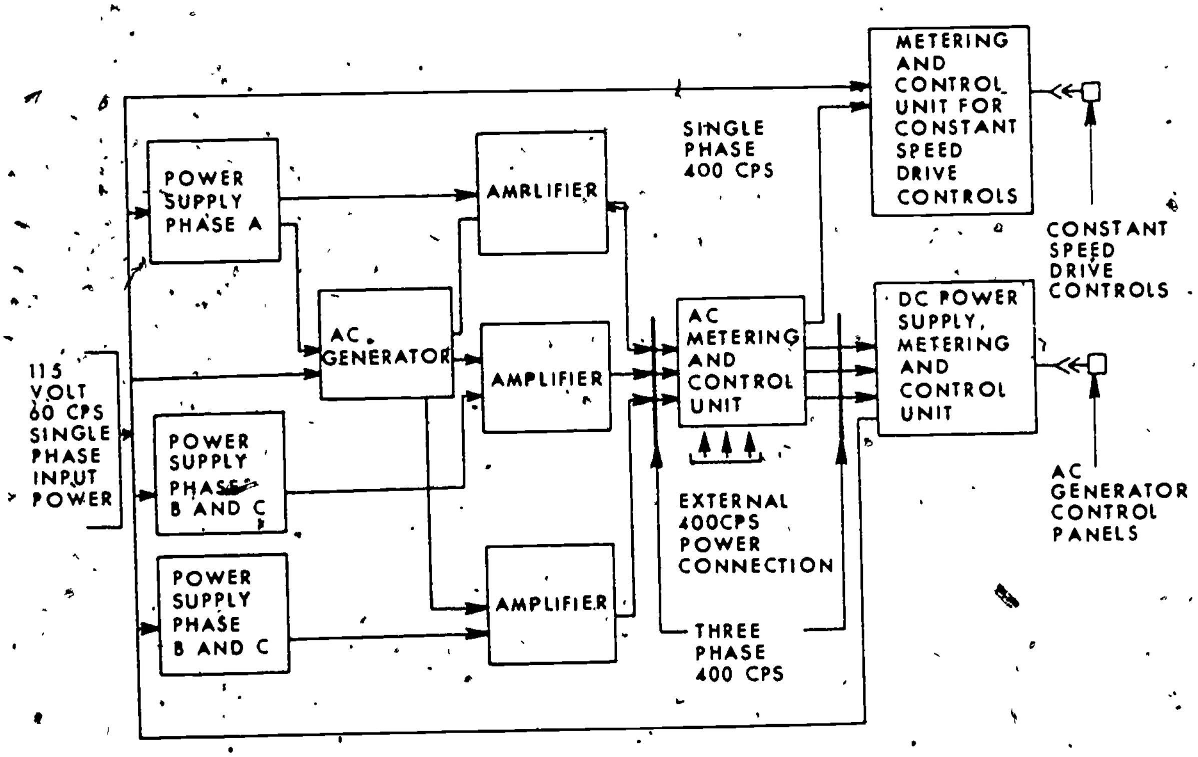


Figure 16. Block diagram of the T-35.

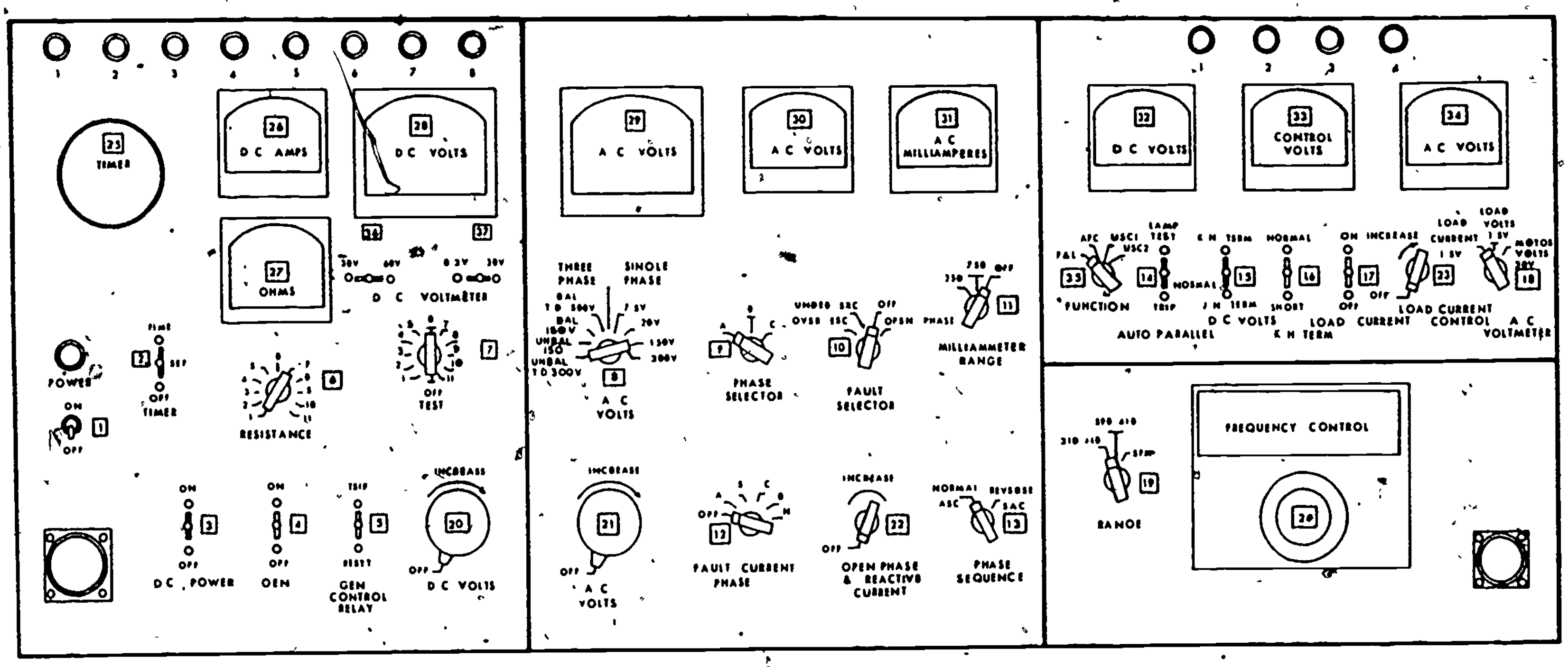


Figure 17. T–35 control panel.

three-phase output. The frequency range of from 310 to 440 Hz uses a resistor-capacitor network for frequency determination, while the frequency ranges of from 390 to 410 Hz and from 4907 to 5760 Hz use an inductor-capacitor parallel resonant circuit for their frequency determination. The single-phase output of the oscillator is connected to a single- to three-phase static converter. These three-phase voltages are fed to the three power amplifiers, as shown in the block diagram, figure 16. For the high-frequency range, the single-phase output of the oscillator is connected to a two-stage cascaded amplifier. This amplifier has a degenerative feedback circuit to improve gain stability. The single-phase voltage is then applied to the power amplifiers for further amplification.

5-16. *Ac metering and control unit.* This unit controls the three-phase voltage, and provides voltages of adjustable levels and correct phases. It incorporates meters for making various voltage and current measurements. The three-phase voltage from the power amplifiers is applied to a three-phase variable autotransformer. The output of this autotransformer is adjustable by the AC VOLTS control, shown in figure 17. Each specific switch position on this unit provides certain operating conditions. When the AC VOLTS switch is in the UNBAL 150 V position, the voltage of the phase selected by the PHASE SELECTOR switch is varied by the AC VOLTS control (autotransformer), while the voltages of the other two phases are held at 115 volts. Other positions of the AC VOLTS switch allow for selecting three-phase balance 150-v, three-phase balance 300-v, three-phase unbalance 300-v, single-phase 7.5-v, single-phase 20-v, single-phase 150-v, and single-phase 300-v positions.

5-17. *Dc power supply metering and control unit.* This unit provides both fixed and adjustable dc power. It incorporates meters for making various voltage, current, and resistance measurements and a timer for determining response times. Indicator lamps are provided for indicating relay contact operation in the unit undergoing test. A fixed dc power supply provides 26 volts dc for operation of the timer clutch and the indicator lamps. The testing procedure can be performed on a typical ac protection panel after the preliminary settings of switches and controls (see fig. 17). A chart giving the preliminary settings is shown in table 2. Each reference number in table 2 indicates the name of the switch or control on the test set. Every item in the ac protection panel can be tested. For example, the generator control relay (GCR) trip circuit may be checked by placing the TEST switch (reference Nr. 7, fig. 17) in position 1 and by turning the dc POWER switch (reference Nr. 3, fig. 17) on and rotating the dc volts control (reference Nr. 20, fig. 17) until the GCR trips and lamp Nr. 2 goes out. The trip voltage may read 18 volts or less on the dc voltmeter (reference Nr. 28, fig. 17). Below are other checks that can be performed on the ac protection panel.

- Undervoltage relay check.
- Overvoltage relay check.
- Overvoltage relay time-delay check.
- Selector relay and bias circuit check.
- Open-phase relay Nr. 1 check.
- Differential protection relay check.
- Control panel test switches check.
- Open-phase relay Nr. 2 check.
- Anticycling relay check.
- Time-delay relay Nr. 1 check.
- Auxiliary relay Nr. 3 check.
- Transformer-rectifier check.

Always refer to the applicable technical order in testing ac protection panels.

5-18. The information which we have presented on the T-35 tester is intended only to acquaint you with the tester capabilities and the functions of the various test set components.

TABLE 2

PRELIMINARY SETTINGS OF SWITCHES AND CONTROLS

MODEL T35 TEST SET

Switch	Reference No.	Position
Power	1	On
Timer	2	Off
DC Power	3	Off
Generator	4	Off
Gen. Control Relay	5	Normal
Resistance	6	Off
Test	7	Off
AC Volts	8	Bal.—150 V
Phase Selector	9	A
Fault Selector	10	Off
Milliammeter Range	11	Off
Fault-current Phase	12	Off
Phase Sequence	13	Normal-ABC
Autoparallel	14	Normal
DC Volts	15	K-H Term
K-H Term.	16	Normal
Load Current	17	Off
AC Voltmeter	18	Motor Volts
Frequency Range	19	390-410
Function	35	F & L
DC Voltmeter	36	30 V
DC Voltmeter	37	30 V
Control	**Reference No.**	**Position**
DC Volts	30	Off-CCW
AC Volts	21	Off-CCW
Open Phase and Reactive Current	22	Off-CCW
Load Current	23	CCW
Frequency Control	24	400 Hz

Also, note that the T-35 tester is somewhat limited when it comes to testing the more sophisticated transistorized ac power system components. A new test set has been developed to provide the means for testing these transistorized power system components, and is designated the T-170 tester.

6. The T-170 Tester

6-1. The T-170 tester is designed to provide a fast and uniform method for testing and adjusting certain ac power-generating system components. However, this tester may be adapted to test other ac power-generating system components by using both a special test lead designed for that component and appropriately punched test cards. As an aircraft electrician, you are responsible for the operation and maintenance of the generator control and protection panels. You must know how to operate this test stand properly to give you a true status (operational status) on equipment panels. The following discussion will acquaint you with various circuits and components within the test stand.

6-2. The test set can test control panels rated at 115/200 volts, 400 Hz, single- or three-phase, and three- or four-wire. The following is a list of the principal tests performed by the T-170 test set:

- Static regulator.
- Overvoltage trip time.
- Undervoltage trip time.
- Undervoltage trip point.
- Differential protection.
- Overcurrent protection.
- Frequency relay calibration.
- Exciter protection.
- Paralleling relay.
- Overexcitation.
- Underexcitation.
- Relay operation.
- Step-change frequency.
- Forward and reverse diode.

6-3. This test set is designed specifically as a general-purpose test set for all control protection panels. Its maximum output is 100 VA volt-ampere per phase. The three-phase voltage is adjustable from 0 to 200 volts, and the single-phase voltage is adjustable from 0 to 150 volts. A fixed and a variable dc voltage are available from 0 to 35 volts, or from 27 to 63 volts.

6-4. **Components.** The test set consists of the following units: ac electronic generator, power amplifiers, amplifier power supplies, power distribution unit, programmer and relay-control center, card switch, voltage-control unit, control dc power supplies, indicator unit, recorder unit, and digital instrumentation system. These units are housed in a desk-type console, as shown in figure 18.

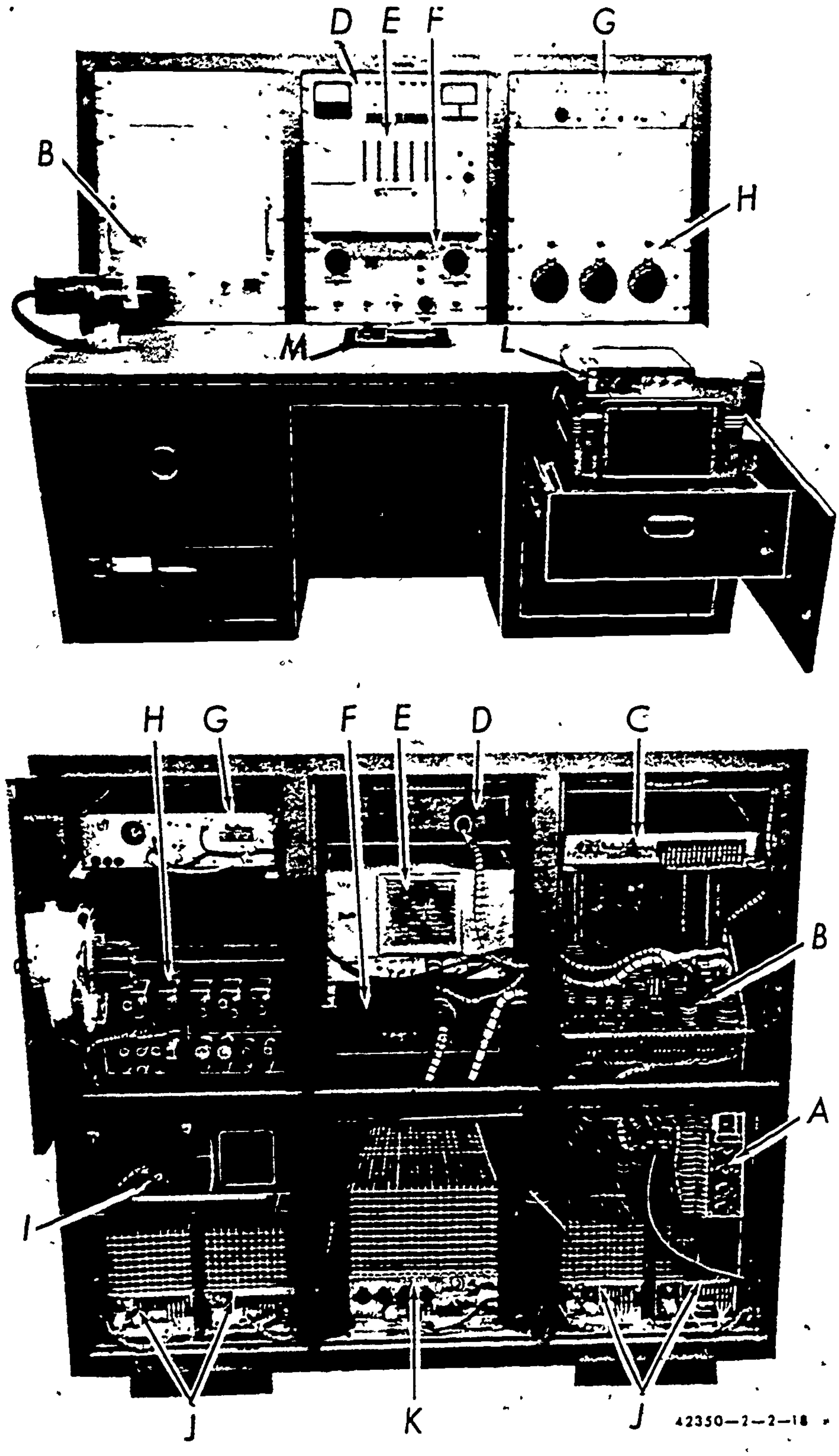
6-5. *Ac electronic generator.* This unit (item H, fig. 18) furnishes variable-frequency signals over two ranges (375–423 Hz and 300–530 Hz), as well as fixed frequencies of 400 and 1600 Hz. There are four individual outputs from the variable-frequency section, each separated by 90° and forming a four-phase system which is transformed to a three-phase system by the amplifier units. This phase relationship is maintained at all frequency settings. The variable frequency is controlled by three dials on the front panel, as shown in figure 18. There are two knobs for the 375–423 Hz range, and provision is made to change from the setting of one to that of the other as a step function might be required for checking the response of generator frequency control panels. The fixed frequencies of 400 Hz and 1600 Hz are used for simulating systems with permanent magnet generators, or for making two generator paralleling tests. The fixed frequencies are single-phase outputs only. All output voltages are regulated.

6-6. *Power amplifiers.* There are four amplifier units (item J, fig. 18), three of which combine the four-phase output from the ac generator unit and produce a three-phase 115/200-volt output. The fourth amplifier is connected to the fixed-frequency output of the ac generator unit. The amplifiers are adjusted for a constant voltage gain of 10 and a very low output impedance, due to the large amount of feedback used in the circuits involved.

6-7. *Amplifier power supplies.* All amplifiers have common power supplies. One unit item I, supplies all the preamplifier stages. The second unit supplies all the output stages (item K, fig. 18). This unit is turned on after a time delay to allow the power tubes to reach operating temperature.

6-8. *Power distribution unit.* This unit (item A, fig. 18), contains the principal 60-Hz input fuses, the time-delay relay, and the power relay to control the amplifier power supply output. An elapsed time indicator is also mounted on this unit. The 115-volt, 60-Hz input power connection to an adjacent terminal block is marked to indicate power and ground connections.

6-9. *Programmer and relay control center.* This unit contains the circuit setup relays and the transformers for applying test signal to the panel on test (item B, fig. 18). The output connector and the test-set power switch are located on the



A. POWER DISTRIBUTION UNIT
B. PROGRAMMER AND RELAY CONTROL CENTER
C. CONTROL DC POWER SUPPLY
D. INDICATOR UNIT
E. ELECTRONIC COUNTER
F. VOLTAGE-CONTROL UNIT
G. CONVERTER VOLTAGE-TO-FREQUENCY
H. AC ELECTRONIC GENERATOR
I. DC AMPLIFIER POWER SUPPLY
J. POWER AMPLIFIERS
K. POWER SUPPLY DC AMPLIFIERS
L. RECORDER UNIT
M. CARD SWITCH

Figure 18. T-170 test set.

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front panel of this unit. Circuits from this unit connect to the card switch, amplifiers, dc power supplies, indicator unit, control unit, and the digital instrumentation system. Wherever possible, plug-in relays are used to facilitate testing and maintenance.

6-10. *Card switch.* This switch is part of the programmer and relay control center (item M, fig. 18). Test cards are placed in the card switch manually. When fully inserted, the card trips a solenoid mechanism which activates the switch. The test set is then programmed to make the test defined by the test card. A set of test cards, attached to the test lead, is required to check out a complete control panel. A set of self-checking test cards is included with each T–170 ac system test set.

6-11. *Indicator unit.* This unit contains on its front panel the indicator lights associated with the circuits through the control panel undergoing test and the indicator lights to show the parameter being checked on the digital instrumentation (item D, fig. 18). This unit, which is located in the top center of the upright panel also contains two auxiliary-indicating meters.

6-12. *Voltage control unit.* The voltage control unit (item F, fig. 18), which is located on the lower center upright panel, contains the voltage control units and the switches which are to be operated after a test card has been inserted in the card switch.

6-13. *Control, dc power supply.* This unit (item C, fig. 18), which is located near the top of the upper left console, contains four low-voltage power supplies. One power supply operates at 28 volts and is used principally for indicator lights and relays. The second supply is operated at a fixed 28 volts and is applied to the panel as required. The third power supply is a variable source of 0–35 volts dc. The fourth supply provides a negative 8-volt bias for use in the timing tests. The operation of the individual power supplies is controlled by the card switch.

6-14. *Recorder unit.* The recorder unit (item L, fig. 18) is a direct-recording oscillograph provided to record the results of dynamic tests on frequency-and-load controllers. The recorder is mounted on a pivoted shelf that swings out of the lower right-hand side of the console and into position.

6-15. *Digital instrumentation system.* This system consists of two parts, a five-digit electronic counter (item E, fig. 18) and a converter, voltage to frequency, item G, figure 18. This system is capable of measuring dc volts, ac volts, frequency, and time intervals over a wide range. The system is automatically programmed by the test card. Frequency and time measurements

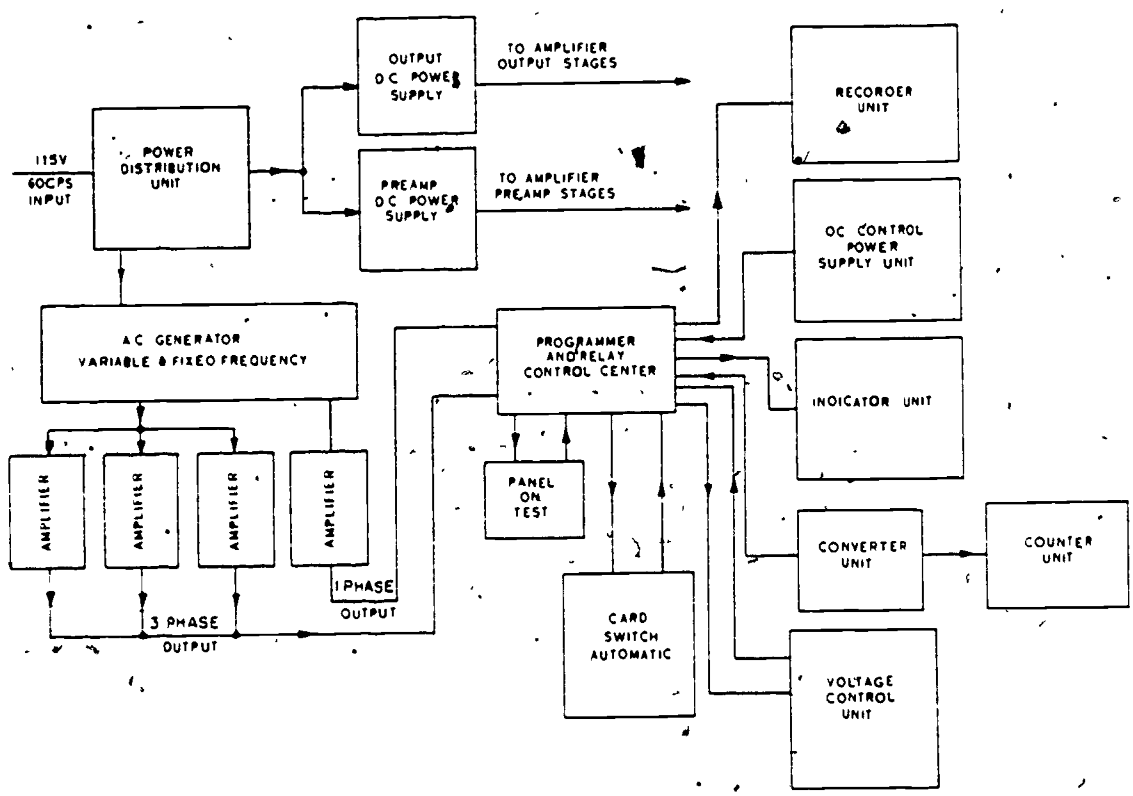

Figure 19. Block diagram T–170 ac system test set.

are made directly on the counter. Voltages to be measured are first applied to the converter, and the resulting frequency is read by the counter, calibrated in volts. Ac voltages are rectified to dc before being converted to frequency.

6-16. **Operation.** As previously mentioned, the input requirement for the test set is for 115-volt, 60 Hz, single-phase power with a maximum load of 25 amperes. The input power is connected to the power distribution unit, and the relationship of the subassemblies is shown in the block diagram of figure 19.

6-17. *Ac electronic generator.* The ac electronic generator (see fig. 19) supplies a variable-frequency four-phase and two fixed-frequency single-phase sine wave voltages. This is accomplished by the use of two oscillator sections.

6-18. *Fixed-frequency section.* This section delivers two stable frequencies of 1600 Hz and 400 Hz. A tuning fork and a triode tube are connected to form an oscillating circuit that produces a precise and stable 1600-Hz signal. This signal is fed into a squaring circuit. As a result, the signal is a 1600-Hz square wave with a peak-to-peak amplitude of 200 volts. From this point the signal takes two paths. One path takes the signal to a clamping circuit. This produces a signal of 10-volt peak-to-peak amplitude which is stabilized against variations. The clamped 1600-Hz square wave is fed to a resonant circuit tuned to 1600 Hz, and the voltage resulting is a 1600 Hz sine wave. This voltage level is controlled by a potentiometer.

6-19. The second path taken by the voltage signal is to a frequency-divider circuit that produces an 800-Hz square wave, which is fed in turn to a second frequency-divider circuit that delivers a 400-Hz square wave. This signal is sent through a clamping circuit that produces a 400-Hz square wave which is stabilized against circuit variations. The clamped 400-Hz square wave is fed to a resonant circuit tuned to 400 Hz, and the voltage resulting is a 400-Hz sine wave. This voltage level is also controlled by a potentiometer.

6-20. *Variable-frequency section.* This section produces frequencies in two ranges, 375 to 420 Hz and 300 to 500 Hz, which are controlled by three dials on the front panel. Two dials are for the 375- to 420-Hz range and one for the 300- to 500-Hz range. Basically, this oscillator consists of five plug-in dc operational-type amplifiers, suitably arranged with resistor and capacitor networks to form an oscillator. In order to cause this resonant circuit to oscillate, a positive (regenerative) feedback signal is required. This feedback is supplied by feeding the output of one amplifier to the input of another. With the regenerative feedback signal coupled to the resonant circuit, the amplitude of oscillation rises to 30 volts root-mean-square (rms).

6-21. In order to control and regulate the amplitude of oscillation, a regulator circuit is included in the oscillator which allows the amplitude to be set anywhere in the range of from 9 to 14 volts by manual adjustment of a potentiometer. This maintains the amplitude nearly constant throughout the frequency range of the oscillator by comparing it to a dc reference voltage. The oscillator voltage is rectified to produce a dc reference voltage.

6-22. Variation of the oscillation frequency is achieved by simultaneously varying a pair of resistors in the oscillator circuit. These are potentiometers attached to the frequency dials. The output voltages which deliver four voltage signals of equal amplitude (one is single-phase and the others form into three-phase voltage output) are connected to the four power amplifiers.

6-23. *Power amplifiers.* Each of the four power amplifiers (see fig. 19) is divided into a voltage-amplifying section and a power-amplifying section. Each section is supplied by a separate power supply. Each amplifier has its own filament power supply. A 100-cubic-foot-per-minute cooling fan is mounted on each amplifier chasis. One of the power amplifiers is used to amplify the single-phase output, and the other three form and amplify the three-phase output from the ac generator. These oscillator output voltages are fed to the voltage-amplifying section through a resistor network which determines the gain of the signals. The voltages are amplified enough to drive the power-amplifying section.

6-24. The power-amplifying section is a push-pull configuration using two power triode tubes. Each tube has a plate power dissipation rating of 100 watts. The tubes are operated with bias that is produced by the voltage drop across each cathode resistor. The electrolytic bypass capacitors in parallel with each cathode resistor, reduces ac degeneration. Thus, the magnitude of the bias for the power triodes is such that the tubes operate at nearly class A until the output power demand rises above 60 watts. At output-power demands above 60 watts, the operating point moves into class AB. The plate power dissipation under no-load is 90 watts per tube. Thus, the operation under these conditions allows the amplifier to develop 100 VA under reactive load without exceeding the power rating of the tubes. The output impedance of each power amplifier is one ohm.

6-25. *Amplifier power supply.* The power for the amplifier units is supplied by two power

units (see fig. 19). One unit supplies power for the preamplifier stages, and the other power supply provides power for the amplifier output stages. Both units have 115-volts, 60-Hz input and a filtered dc output.

6-26. *Power-distribution unit.* This unit provides the means of distributing the input power to the various units of the test set. The power supplied to the output dc power supply for the amplifier-output stages is fed through a time-delay circuit that allows the filaments to become properly heated before the plate power is applied to the amplifier-output tubes. Otherwise, damage to these tubes might result. Another power source coming from the power distribution unit provides 26-volts, 60-Hz ac for the start-test indicator located in the programmer and relay control center.

6-27. *Programmer and relay control center.* This unit, as shown in figure 19, contains relays and transformers which form a connecting point for the card switch, indicator unit, voltage-control unit, and power supply.

6-28. *Card switch.* This switch is an electromechanical device including 186 sets of contacts, used to select the circuits of the test set to be used in a particular test. Individual sets of contacts are opened by means of a punched card placed in the switch. The sets of contacts are opened when a hole is present in the card and the switch mechanism is operated. The switch mechanism is activated by a solenoid that is located at the rear of the card slot. Placing the punched card fully in the slot automatically operates the card switch. Thus, the circuits that are not needed in a particular test are made inoperative by the test card.

6-29. *Indicator unit.* This unit includes a set of six numbered indicator lamps that indicate the circuit of the panel under test. A dc voltmeter and dc ammeter are also provided. The voltmeter may be used as an ohmmeter to test diodes or perform continuity and resistance measurements.

6-30. *Voltage-control unit.* This unit contains most of the operating controls needed during test procedures. Two voltage controls are provided. One is a single-phase variable transformer which is used to control the dc voltage level on the ac bias voltage level. The other, a three-phase variable transformer, is used to control the three-phase ac voltage. The unit also contains a PHASE-SELECTOR switch that permits monitoring each of the three phases of the ac voltage individually. Additional switches are provided to control the panel under test. The trip switch and reset switch apply dc voltage to the trip and reset coils of the generator control relay. The set test switch, in the SET position, arranges circuits that permit the presetting of various voltage conditions which are then applied to the control panel when the switch is placed in the TEST position.

6-31. *Control dc power supplies.* This unit contains four separate dc supplies used for control purposes. One provides biasing for the timing circuits. This supply operates from a 60-Hz ac source. Another is used to operate indicator lamps and relays. A third is used to supply control power to the panel under test. The last one is a variable dc supply which may be operated from either a regulated 60-Hz or 400-Hz input.

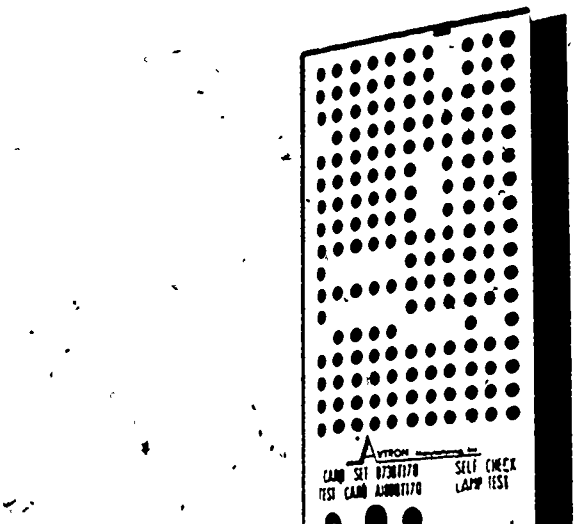

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Figure 20. T-170 test punch card.

This supplies variable control power to the panel under test.

6-32. *Recorder unit.* This direct-recording oscillograph is equipped with two active galvanometers and two static traces used as reference lines. One channel may be used to display the output of the frequency-and-load controller to the magnetic governor trim coil, and the second channel may be used for timing to show the application of step changes during transient tests.

6-33. The T-170 tester is used in testing the frequency-and-load controller unit. The preliminary settings of all the controls should be at their initial positions. In testing the load-division circuit. the applicable punchcards are inserted in the punchcard receptacle. A typical test punchcard is shown in figure 20. Other circuits in this unit that may be tested are:

- Frequency-control circuit.
- Output linearity and gain of the frequency-control circuit.
- Load-division null potentiometer adjustment and gain potentiometer setting.
- Synchronizing relay test.

6-34. This concludes the discussion on the T-170 test set. Both the T-35 and the T-170 test sets are designed to test various ac power-control system components. From our discussion of these testers, you can see that they provide the various operating conditions found on the aircraft, but they do not provide a means of testing the constant-speed drive (CSD) on the generator.

6-35. The next tester that we consider, the MC-2 test stand is designed to test both the CSD and the generator. The MC-2 test stand also provides another means of testing system components.

7. The MC-2 Test Stand

7-1. The MC-2 test stand, shown in figure 21, is designed for field-testing constant-speed transmissions, their 400-Hz ac components, and certain ac generators. The test stand uses power from a three-phase line operating at a voltage of either 220 or 440 volts line-to-line at a frequency of 60 Hz. The power unit is provided with dual heads or power take off shafts, the speeds of which are proportional to each other through the speed ranges. The low-speed head may be varied from 2000 to 7500 rpm, and the high-speed head may be varied from 2400 to 9150 rpm.

7-2. **Components.** This test stand consists of a shield, skid-type base, control console, variable-speed main prime mover, auxiliary variable-speed start prime mover, and instrumentation and controls.

7-3. *Start prime mover.* The auxiliary variable-speed prime mover has a 5-hp continuous rating and provides suitable means for slow starts of the main variable-speed prime mover. A magnetic clutch provides for automatically disengaging the start prime mover from the main prime mover when the latter is energized. Acceleration of the start prime mover is at a fixed rate of approximately 125 rpm per second, and suitable controls for starting and stopping and for increasing (item G, fig. 21) and decreasing (item F, fig. 21) the speeds are provided on the speed control panel. The speed range of the start prime mover is from 145 to 975 rpm, measured at the output shaft of the low-speed head, and from 175 to 1190 rpm on the high-speed head. The speed of both heads (HIGH A, figure 21 and LOW B, figure 21) is indicated on the speed control panel. A 1/15-hp control motor provides remote speed control for the start prime mover.

7-4. *Main prime mover.* The main prime mover assembly has a 75-hp continuous rating and is used for powering constant-speed transmissions during testing. Acceleration of the main prime mover is at a fixed rate of approximately 800 rpm per second, and the controls for starting and stopping and for increasing (item D, fig. 21) and decreasing (item E, fig. 21) speed are also located on the speed control panel (see fig. 21). A 1-hp-geared head motor with an output speed of 350 rpm is mounted to the frame of the prime mover assembly and is connected to the control shaft of the main transmission. A magnetic brake is connected to a 1-hp control motor. This brake stops the control motor the instant either the INCREASE or DECREASE button (items D and E of fig. 21) for the main prime mover is released. When either of these buttons is pressed, the magnetic brake releases.

7-5. *Limit switches.* Both the 5-hp start prime mover and the 75-hp main prime mover are equipped with limit-switch assemblies to control their high-speed and low-speed limits through their respective control motors. The high-limit switch on the 5-hp prime mover is set to break the circuit to the 1/15-hp control motor when the output speed has reached a preset maximum. The low-limit switch is set to break the circuit to the 1-hp control motor when the maximum or maximum speed has been reached on that unit.

7-6. *Hydraulic circuit.* An oil reservoir with a capacity of approximately 12 gallons is located behind the hydraulic access door. This charge oil reservoir is equipped with a sight gage or level indicator (item C, fig. 21), which is visible on the hydraulic panel. A second reservoir for preservative oil is located behind the first reser-

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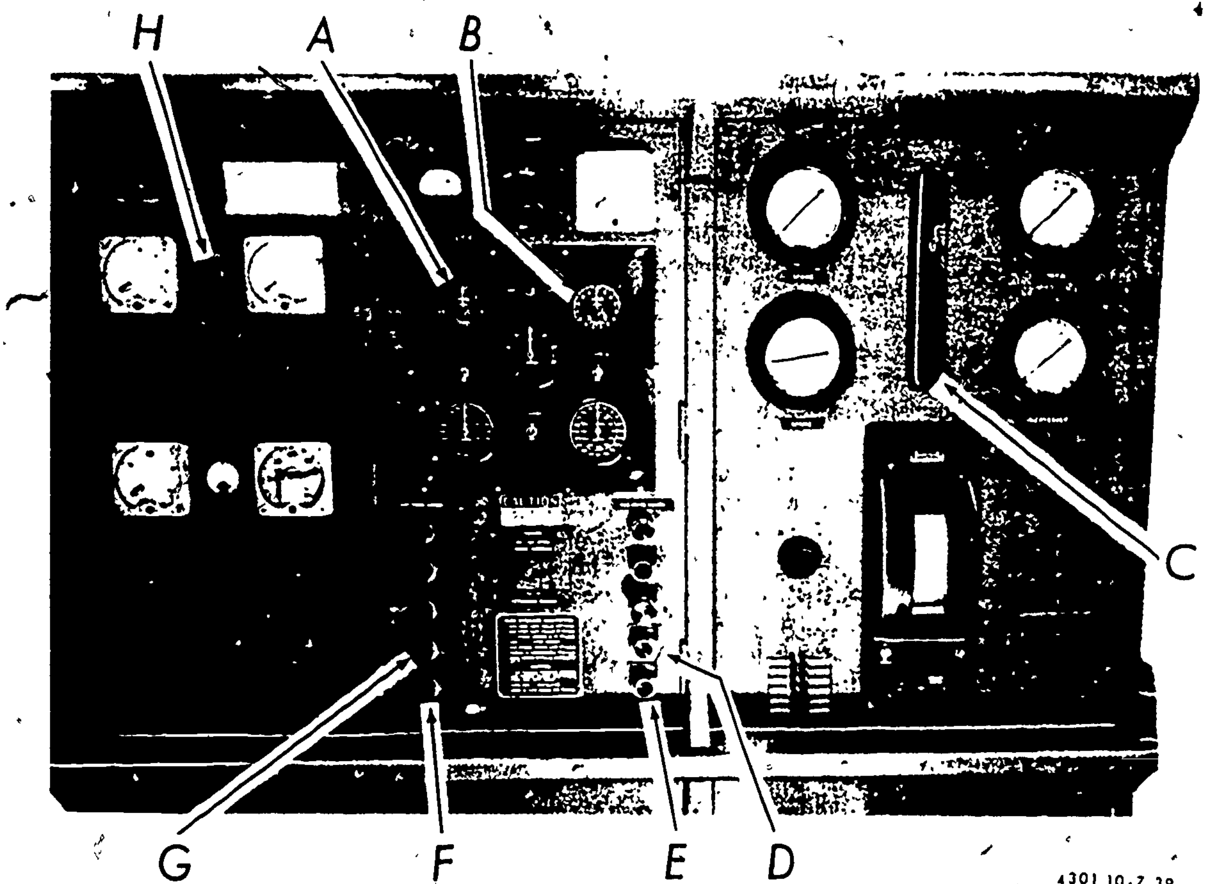

A. HIGH-SPEED RPM INDICATOR
B. LOW-SPEED RPM INDICATOR
C. CHARGE OIL RESERVOIR OIL SIGHT GAGE
D. MAIN PRIME MOVER INCREASE BUTTON
E. MAIN PRIME MOVER DECREASE BUTTON
F. START PRIME MOVER DECREASE BUTTON
G. START PRIME MOVER INCREASE BUTTON
H. SYNCHRONIZING LIGHTS

Figure 21. MC-2 test stand.

voir, and is equipped with a sight gage (item B, fig. 22), which is visible at the drive mounting end of the test stand (fig. 22). As various transmissions require different oil-in temperatures, an electric heater, controlled through a "Mercoid" switch temperature controller, is located in the hydraulic circuit between the oil cooler and the reservoir. The temperature controller range is from 30° to 120° C. Another temperature controller (item A, fig. 22), mounted on the center dividing panel behind the hydraulic control panel, causes the test stand to shut down if the oil in the reservoir becomes too hot. Oil in the hydraulic circuit travels from the oil reservoir through the flow indicator oil input valve and charge oil filter to the dual quick disconnects marked OIL FROM RESERVOIR (item C, fig. 22) After passing through the transmission, oil travels from the dual quick disconnect marked OIL RETURN (item D, fig. 22), through the scavenge oil filter, oil-out valve, oil cooler, oil heater, and flow indicator, back to the reservoir.

7-7. *Control console.* All the components of the test stands are accessible for maintenance and adjustment through the doors and the removable panels. The controls and instrumentation on the control console are arranged on two doors and one panel, as shown previously in figure 21. They are a 400-Hz ac control door, 60-Hz ac and speed control door, and hydraulic panel. A chronotachometer containing two rpm indicators, two revolution counters, and a minute counter is located on the 60-Hz ac and speed control door.

7-8. *Adapter kits.* Before using the field test stand for testing an aircraft system, the proper adapter kit must be installed. There is a different adapter kit for each system. You find instructions for installing the various adapter kits, as well as for mounting transmissions and ac generators, in the applicable technical order. All wiring harnesses and other components necessary for adapting the test stand to an aircraft system are included in each kit.

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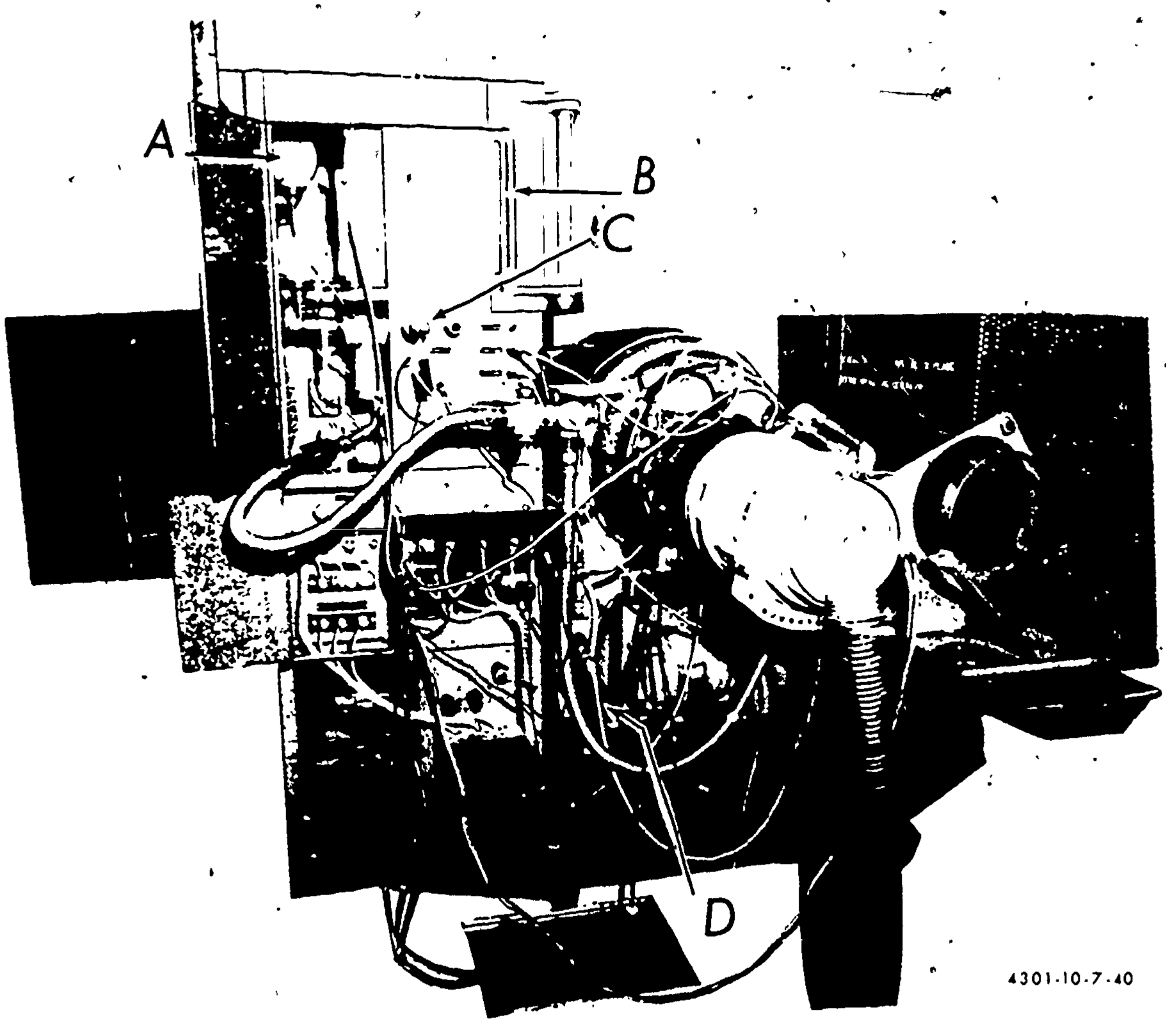
7-9. **Operation.** Always refer to the applicable technical order for operating instructions. When the 5-hp unit "start" prime mover produces maximum acceleration, then the 75-hp unit "run" prime mover may be engaged. There will be an immediate speed increase to approximately 2000 rpm on the low-speed rpm indicator (item B, fig. 21) on the chronotachometer, and to 2440 rpm on the high-speed head, as shown by the high-speed rpm indicator (item A, fig. 21). The 75-hp INCREASE button (item D, fig. 21) may then be used to bring the speed of the prime mover to the desired rpm.

7-10. When the prime mover speed has reached the minimum rpm necessary for the system being tested, the ac generator may be excited. Exciting the ac generator automatically places the ac generator on the bus for some applications. When this is the case, the LOWER two synchronizing lights (item H, fig. 21) will come on with a bright steady light, and the top synchronizing light will not light. If all the synchronizing lights begin flashing on and off in rotation, it indicates that the ac generator is excited but not on the bus. Pressing the MANUAL C-B CLOSE button will place the ac generator on the bus. A load bank connected to the bus will check the ac generator under load. Normally, a load bank is not provided with the field test stand or with the adapter kits.

7-11. An A-1 load bank is used with the MC-2 test stand. The load bank provides all of the necessary loads to test ac generators. At this point we will discuss the A-1 load bank.

8. The A-1 Load Bank Tester

8-1. This tester is primarily designed to provide a means for load testing aircraft type four



A. OVER TEMPERATURE CUTOFF
B. PRESERVATIVE OIL RESERVOIR SIGHT GAGE
C. OIL FROM RESERVOIR QUICK DISCONNECT AND HOSE
D. OIL RETURN QUICK DISCONNECT AND HOSE

Figure 22. MC-2 test stand mounting end.

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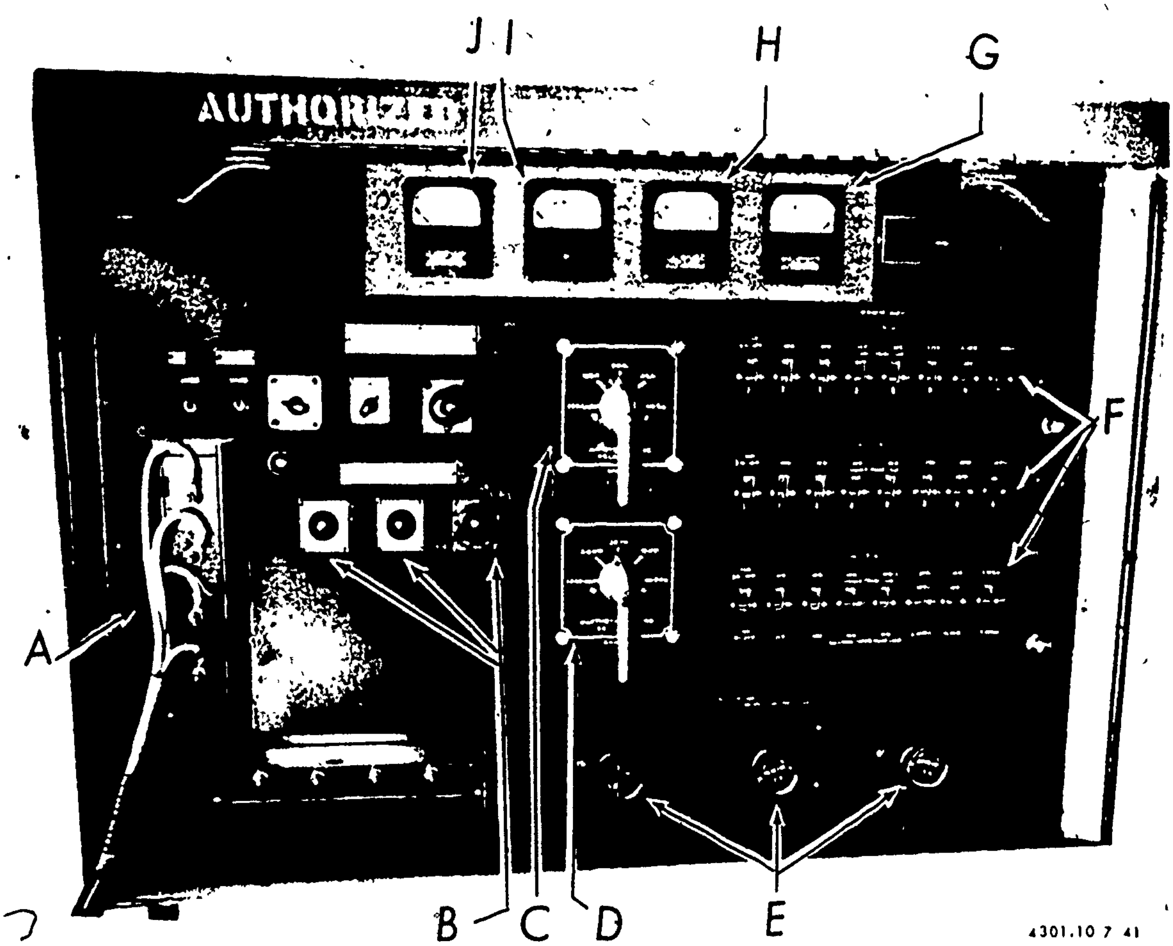
wire ac generators with a 120/208 volt, three-phase, 400 Hz rating. The load bank is fully equipped to apply either resistive loads up to 60 kw or reactive loads up to 40 KVAR, as required by the test specifications of the manufacturer. The complete assembly consists primarily of an all-steel housing into which are assembled all components required by the load bank assembly for carrying out required tests. Instrumentation, connection, and controls are conveniently grouped on a common instrument panel within easy reach when you are standing in a normal position in front of the unit. The entire unit has been designed to fit on the bed of a type K–1 trailer.

8-2. **Circuit.** The tester consists of a number of electrical components whose functions are directly related and closely coordinated. The entire electrical supply is from the ac generator under test, and no external source of power is required. We will discuss the circuit as a series of subcircuits for the sake of clarity. In the following paragraphs, refer to figure 23 for reference to items.

8-3. **Reactive Load.** The loading circuit is based on three-phase operation, with each phase individually loaded. Since the normal operational load of the test component probably never will be purely resistive, means are provided to apply a total reactive load up to 40 KVAR. The load is variable to 13.3 KVAR in each of the three legs. When the four leads from an ac generator are connected to the terminal points T1, T2, T3, and N (item A), the power is applied to a reactive load composed of three coils (saturable reactors). Each phase is loaded independently from the front panel by means of three rheostats (item B) which shunt the reactors and control the reactors. Three variable wire-wound resistors are



A. T1, T2, T3 AND N TERMINAL POSTS
B. REACTOR LOAD-CONTROL RHEOSTATS
C. AMMETER RANGE SELECTOR SWITCH
D. WATTMETER RANGE SELECTOR SWITCH
E. RESISTIVE LOAD CONTROL RHEOSTAT
F. RESISTIVE LOAD CONTROL RHEOSTATS
G. POWER FACTOR METER
H. WATTMETER
I. AMMETER
J. VOLTMETER

Figure 23. A–1 load bank.

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preset at the factory and are locked in place. They provide a means for making calibration adjustments in the circuit. To insure that there will be no current flow in the circuit under no-load conditions, the lines from the load coils are opened by means of switches which deenergize their relays. The three switches are actuated by the loading controls. When pure reactive loads are desirable, all of the resistive loading switches must be in the OFF position. On the other hand, to obtain a pure resistive load, the reactive loading controls must be in the OFF position.

8-4. **Resistive Load.** The three phases of the ac generator may be worked into a purely resistive load. The load is variable up to 60 kw with 20 kw in each phase. The loading of each phase is completely independent of the other two phases. The load for each phase consists of a parallel network of resistors which is identical to the network for the other two phases. The networks are physically mounted on two resistor banks, but electrically they appear as the resistive loads. Each network consists of eight resistive steps connected in parallel across the line and neutral busses and put into the circuit by the appropriate snap-action loading switch for its respective stop. The eight resistive loading switches (item F) of each leg are identical to the load switch, a single-pole, single-throw switch. A rheostat resistive load control, (item E) in series with a resistor section, permits a variable 0-.4 kw load to be placed on the ac generator by the 0-.4 kw load switch. A resistor section and its switch permit a fixed 0.-4 kw load on the ac generator. Each of the resistor sections places a 0.8 kw load on the test unit when its respective switch is closed. Similarly, four switches add additional load increments of 1.6 kw, 3.2 kw, and 6.4 kw when closed, by placing resistor sections respectively in the load circuit. The other two load networks are identical and permit independent loading of each phase from 0 to 20 kw, and also permit a balanced three-phase load from 0 to 60 kw.

8-5. **Ammeter Circuit.** The ammeter circuit provides you with a means for measuring the current flow in each of three phases and consists primarily of the ammeter (item I), the three-section range selector switch (item C), the PHASE SELECTOR switch, and three current transformers.

8-6. The ammeter is normally shorted out of the circuit until the range selector switch has been moved to the maximum range position; there the switch is closed, energizing the two-section relay, which opens the short across the ammeter and also closes a holding contact that keeps the solenoid energized after the range switch is moved to the lower ranges. The range selector switch is a three-pole, five-position, heavy-duty, rotary-type industrial switch which varies the primary winding of the three current transformers. The secondary windings of the current transformers are applied to the PHASE SELECTOR switch which controls the phase input to the ammeter.

8-7. **Wattmeter Circuit.** The wattmeter circuit provides a means for measuring the power produced by the ac generator. The circuit consists of three current transformers, a wattmeter range selector switch, (item D), a wattmeter (item H), a WATT-VARS switch, a phase shift transformer. and a resistance box. The current coils of the wattmeter are normally shorted out of the circuit until the selector switch has been moved to the HIGH-RANGE position. In this position the switch is closed, energizing the four-section solenoid which opens the three shorting lines across the current section of the wattmeter. The contacts of the fourth set are used as holding contacts to keep the solenoid energized after the selector switch has been moved to a lower range. When you press the WATT-VARS selector switch to the VARS position, the phase-shift transformer will be placed in the voltage leads to the wattmeter so that the reading of the meter is reactive volt-amperes rather than watts.

8-8. **Voltmeter Circuit.** A voltmeter circuit is provided so that the line-to-line and the phase voltages can be measured. It consists of a voltmeter (item J), a selector switch, and a multiplier. The selector switch is a three-pole, six-position rotary-type which connects the voltmeter across the potential to be measured. In measuring the line-to-line potential, the switch puts the multiplier in series with the meter, while in measuring the phase voltage, it shorts the multiplier out of the circuit. This provides automatic range selection in the shifting from phase voltage measurements to line-to-line voltage measurements.

8-9. **Power Factor Meter Circuit.** The power factor meter circuit provides you with a means for measuring the amount of phase shift between the line voltage and the line current. The circuit consists of the power factor meter (item G), and voltage-dropping resistor box. The input to the meter is the line-to-line voltage and the current flow in one leg of the input of the ac generator to the test unit; therefore, its readings are accurate only with a balanced load.

8-10. **Ventilating Fan Circuit.** Fans are provided to prevent overheating of the load bank components during tests. The circuit consist of the cooling fans, a manual thermostat switch, two condensers, and the thermostats. The thermostats are normally open, maintaining an open

supply circuit to the fans. When the temperature within the cabinet has reached 32.2° C. (90° F.), the thermostats close, and the direct current potential from a dry disc rectifier is placed across the fans. The thermostat switch permits you to short out the thermostats when the cabinet temperature fluctuates rapidly around the set point of the thermostats and results in erratic and intermittent operation of the fans. The fans operate continuously when this switch is closed. The capacitors suppress arcing at the thermostat contact points.

8-11. **Control Supply Circuit.** The dry disc rectifier supplies the dc power needed to operate the control circuit. This circuit provides both the power used in varying the reactive load on the ac generator and the power for the various relays. Each of the saturable reactors used to load the ac generator consist of a loading coil and a control coil, closely coupled by a core element. The flow of dc current through the control coil will vary the test load being applied to the ac generator. The use of a rheostat in series with the control coil permit you to vary at will the reactance in any leg of the load bank. The holding leg of the load coils are energized by toggle switches so mounted on the rheostat that in the OFF position the respective relays are deenergized and the contacts open the leading coil circuits.

8-12. **Connections.** The instrument panel is equipped with eight terminal posts to permit you to make connections with the ac generator to be tested and to permit the connection of an external lead when necessary. The connections from the ac generator are to the input terminal posts T1, T2, T3, and N. Since the ac generator is a "Y" or star type, the N post is the neutral or ground wire and is grounded to the cabinet assembly ground connection within the load bank. The external load terminal posts 1, 2, 3, and N permit you to connect an external lead to the ac generator while using the load bank instruments for measuring the performance of the ac generator and the load applied. Always refer to the applicable technical order for operation instructions. Never attempt to make connections to an ac generator or to a load bank terminal while the ac generator is in operation. Never touch any terminal posts with the ac generator in operation.

9. L–1A Inverter Test Stand

9-1. Up to this point we have been talking about equipment that is used to test aircraft generator systems. The next tester to be examined is the L–1A inverter test stand. In the present day Air Force, the inverter has been taking a backseat to the ac generator in the production of ac power. The responsibility delegated to the inverter is now one of emergency ac power production. This means, that when needed, it is necessary for the inverter to work properly. Irregular working conditions such as these make the testing of the inverter a very important phase of maintaining the system. The tester should indicate the weak areas in the inverter, plus, determine malfunctions when the component is inoperative. Testing of the inverter before and after repair minimizes component failure after the item has been installed on the aircraft.

9-2. You use the L–1A inverter test stand to test inverters up to a maximum output of 2500 volt-amperes at a unit power factor. You accomplish this testing by measuring the input voltage and current and the output voltage, current, and frequency of the inverter under test.

9-3. **Description.** The L–1A is a compact tester which requires a 5-KW voltage source of dc power to test all inverters up to, and including those with a 2500 volt-ampere output. The tester consists of a panel assembly mounted on the front of the cabinet assembly, a load bank mounted in the rear of the cabinet assembly, and storage compartment for the cable set assemblies. Meters and control switches are mounted on the panel assembly for checking the dc input voltage and current and the ac output voltage, current, and frequency.

9-4. **Operation.** The tester is designed so that any inverter, either single-phase or three-phase delta output may be connected by means of a suitable cable set. There is a "live circuit" which supplies current to the filament heaters of tubes used in the control circuits of some inverters. This circuit provides a means of automatically applying power to the tube heaters before the dc power switch is turned ON. Thus, the inverter is protected at all times.

9-5. You should check the test stand to insure that all switches are in the OFF position. Select the proper cable set and connect the inverter to the tester. With the dc ammeter range switch in the START position and the dc power switch ON, the inverter should run. The dc ammeter range switch can then be rotated to the desired range and the voltage and current draw of the inverter will be indicated on the dc meters. Conduct all tests while making constant reference to the technical order on the specific inverter being tested. Position both the dc ammeter range switch and the ac ammeter range switch to a range higher than encountered by normal current flow before applying a load to the inverter. The load switch is then positioned to either the ONE-PHASE or THREE-PHASE position. You ap-

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ply a load to the inverter by rotating the load control knob in a clockwise direction. To obtain voltage and current readings on a single-phase inverter, place the volts/amps switch in the N position. You obtain the output phase readings for a three-phase inverter by placing the switch in either the "A", "B", or "C" position.

9-6. The output voltage, current, and frequency must be within limits under varying loads as prescribed in the technical order. When you complete the test, return all switches to the OFF position and disconnect the inverter from the tester.

10. Component Testing

10-1. In this chapter we have discussed the various items of test equipment available to the electrician for testing ac power system components. This discussion did not include detailed operation of the test equipment, nor will our discussion in Chapter 3 of component testing include the detailed procedures for performing each test. Rather, it will deal with the general requirements for component testing.

10-2. The biggest single factor to consider when a system malfunction is reported is component operation. In most cases, when a component is suspected of malfunction, it must be removed from the aircraft and sent to the shop for testing. You may do the testing yourself, or the shop may have a designated individual to perform the required tests. In either case, you should be aware of the test requirements. At this point, let us discuss these requirements.

10-3. **Test Requirements.** Stated simply, the requirements for testing a component are determined by the function or functions that it must perform when installed in a complete system. In other words, if a component such as a generator is required to provide a given output under various speed and load conditions, this then determines the test requirements for that generator. The basic rating of the generator determines how much load and at what speed the generator will carry it. However, the technical order for the generator being tested specifies the specific requirements with respect to the speed and load conditions, the type of test stand that should be used, and the cooling requirements while the generator is under test. You find, and may use, suggested test data sheets in the technical order for recording the tests. You may also use similar data sheets provided data can be recorded as specified in the tests. Under no condition should you perform a functional test on a system component without referring to the applicable technical order.

10-4. **Testing.** Selection on your part of the proper test equipment is a must for the testing of aircraft ac power system components. The testing procedure is an exacting process and must duplicate the exact operating characteristics to be found on the aircraft.

10-5. A complete functional test is required any time a unit has been overhauled, suspected of malfunction, or before and after repair. If for any reason you stop a functional test before it is completed, you must repeat the full sequence.

10-6. An important part of testing is the minor adjustment of the various components during the test. If for any reason timing functions are not correct, or voltage reads high or low, take immediate steps to correct these conditions before going on with the test.

CHAPTER 3

DC Generator System

IN THIS CHAPTER we will discuss dc generator systems. The information you learn from this chapter will be of great value to you when performing everyday duties as an electrician. You should always refer to the proper technical order for a particular generator system. However, this discussion will provide you with the background knowledge required to troubleshoot, test and maintain any generator system. A typical generator system will consist of a generator, voltage regulator, overvoltage relay, field control relay, and reverse current relay. These are the components we will discuss at this time.

11. DC Generator

11-1. The operation of most electrically operated equipment in an aircraft depends upon energy supplied by a generator. A generator is a machine that converts mechanical energy into electrical energy by electromagnetic induction. In aircraft using dc electrical systems, you will find one or more dc generators supplying this power. Before we get too far, let's start with a quick review of the operating principles of a generator.

11-2. **Simple Generator.** You should remember from Tech School and the review in Volume 1 that when there is relative motion between a conductor and a magnetic field there is a voltage induced in the conductor. With this in mind, we will look at a simple generator.

11-3. The simplest generator field is built like the drawing in figure 24. Two electromagnets are mounted in a circular iron frame called a yoke. These electromagnets are wound so as to produce opposite polarity. Notice how the magnetic circuit is entirely in iron except at the center, between the poles. This area between the pole pieces is the only part of the field outside the iron.

11-4. The yoke, its pole pieces, windings, and the field produced are the primary circuit. The secondary circuit is a coil wound on an iron core. The coil and the core are mounted on a shaft and the assembly is called the armature. Figure 25 shows a typical armature. To make the generator complete, the armature fits into the area between the pole pieces. The yoke of the generator stands still and thus the field of flux is steady and stationary. The armature shaft is rotated by a source of mechanical power and, as the armature is rotated, the conductors of the coil cut through the magnetic field flux. In the simplest as well as in the most complex systems, armature conductors cutting flux produce an induced voltage. As you know, rotating coils produce alternating voltage. This will never work because we wanted dc. What shall we do then? . . . We should not forget one more part of the armature, the commutator. This changes the ac produced by the rotating coils to dc which is delivered to the generator terminals. Now that you have reviewed the construction of a simple generator let's move on to more complicated ones.

11-5. **Generator Types and Field Distortion.** Generators are normally classed two ways. First by means of excitation and second by the relationship of the field winding to the armature. As to excitation, they are either excited externally or they are self-excited. This last class will be our point of discussion.

11-6. All generators employed on aircraft are known as self-excited generators. In any type of self-excited generator, successful operation depends upon the retention of a small amount of magnetism in the iron pole pieces, even when no current is flowing in the field coils. This is called residual magnetism. With residual magnetism available, the armature, when rotating, cuts a few lines of force and induces a small voltage in the armature windings. If this voltage were applied to the generator coils, it would cause a current to flow in those field windings, which, in turn, would build up the strength of the magnetic field within the generator. The increased field strength, in turn, results in a higher voltage, and this results in an increased current flow through the field coils. This process is called

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self-excitation, as no outside source of energy is used to create the magnetic field.

11-7. The second classification we mentioned was the relationship of the armature to the field windings. In this classification we will discuss (1) series-wound (2) shunt-wound, and (3) compound-wound.

11-8. *Series-wound generator.* In the series-wound generator, the field coils are connected in series with the armature. The current in the load, which is connected externally, also flows through the field coils. Since the magnetic field strength is proportional to the load current, a varying load would result in a varying output voltage. In other words, as the load increases the terminal voltage increases, and as the load decreases the terminal voltage decreases. Because the electrical and electronic equipment installed in aircraft requires a constant voltage, the series-wound generator cannot be used.

11-9. *Shunt-wound generator.* A shunt-wound generator is one that has its field coils connected in parallel with the armature terminals. The shunt-wound generator produces the greatest terminal voltage under no-load conditions. As the load increases, more current flows through the load and less through the field; and the terminal voltage decreases.

11-10. Let's discuss why this undesirable condition occurs. The output voltage under load is equal to the no-load terminal voltage less the voltage drop across the armature. As the load increases, greater current flows through the external load and the armature. This greater current through the armature increases the voltage (IR) drop across the armature and reduces the terminal voltage. The reason is that a larger quantity is subtracted from the no-load terminal voltage and the difference or terminal voltage under load is decreased. This smaller voltage

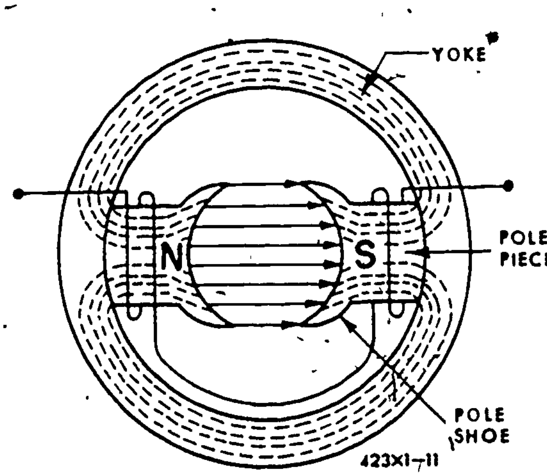

Figure 24. Generator magnetic circuit.

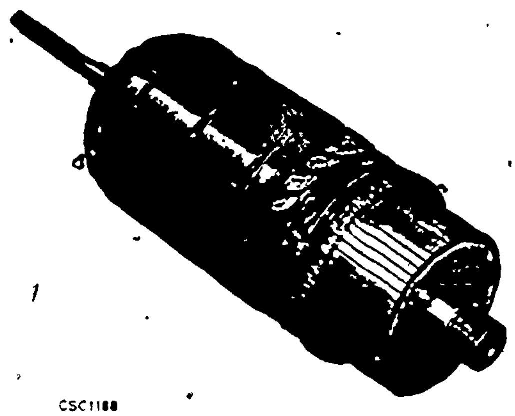

Figure 25. Generator armature.

sends less current through the field, and the resulting decreased magnetic field strength reduces the output voltage.

11-11. *Compound-wound generator.* A compound-wound generator has both a series field and a shunt field. The shunt field coils are connected across the armature, as in the shunt-wound generator previously discussed. The series winding is connected in series with the load. The series windings are wound onto the pole piece. so that the magnetic flux they produce is added to the flux produced by the shunt winding. Therefore, since the series field is in series with the load, the same amount of current flows in the load circuit as in the series field windings. When the load increases, more current flows through the series field windings, causing an increase in the strength of the field in which the armature rotates. This action tends to increase the generator output. The shunt winding acts as it does in a regular shunt-wound generator; i.e., the terminal voltage tends to decrease as each load increases; the two actions are opposite in effect and the terminal voltage remains the same. This is exactly what you are looking for in a generator. In almost every case where a constant voltage under varying loads is needed, you will find a compound-wound generator used.

11-12. *Field distortion.* Now, let's discuss armature reactance, because it plays a large role in determining the output of all dc generators.

11-13. In a dc generator, the current flowing through the armature sets up a magnetic field about the armature windings. This magnetic field tends to distort or bend the magnetic flux between the poles of the generator. Since the armature current naturally increases with load, this distortion becomes more pronounced as the load increases. In this event, a voltage is induced into the shorted windings and considerable sparking takes place between the brushes and the com-

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mutator segments. This excessive sparking not only burns and pits the commutator, but it causes excessive wear on the brushes themselves. Since this is an undesirable condition, let's discuss the most common methods of reducing excessive brush sparking.

11-14. One method of reducing field distortion is by adding interpoles to the generator. An interpole is a pole placed between the main poles. It has the same polarity as the next main pole in the direction of armature rotation. The magnetic flux produced by an interpole cancels out the emf of self-induction in the armature as each armature winding passes under the interpole. This means that armature reaction is lessened considerably.

11-15. Another means of reducing armature reaction is provided by the slotted pole pieces. A slotted pole piece is nothing more than a series of slots, or airgaps, cut in the face of each pole so that more iron is replaced by air, with the result that the effects of the armature magnetic field are weakened. The main magnetic field is not weakened. Since the armature flux cannot avoid the airspaces, it is weakened to the point that it scarcely interferes with communication.

11-16. Still another method of reducing armature reaction is through the use of laminated pole tips. A laminated pole tip is one in which every other lamination is reversed, leaving a series of airgaps on the tips of each pole. By reducing the amount of iron at the tips of the poles, a concentration of flux at the pole tips is prevented, thus reducing distortion.

11-17. The last method we discuss is that of using compensating windings to reduce armature reaction and the effects of self-induction. The compensating windings are placed so that they overlap the main poles and are in series with the armature. You already know that when the load current is increased, the armature flux also increases. Since the compensating windings are in series with the armature, they produce a flux that is opposite to the armature flux; therefore, the result is almost complete cancellation.

11-18. Now that you have refreshed your memory as to the operating principles of dc generators, let's turn our discussion to the maintenance you will be performing on dc generators.

11-19. **General Maintenance Requirements.** When you are working at maintenance levels where generators are disassembled, you may perform various electrical tests on the components of each generator to determine their serviceability. For the exact measurements of components on a particular generator refer to the *Overhaul Instructions* technical order for that particular generator.

11-20. *Commutator.* The commutator is constructed of a large number of individual copper segments, each of which is electrically insulated from the others and from the other parts of the armature by mica insulation. After the completed armature is assembled, it is placed in a machinist's lathe, and a skilled machinist turns the commutator to a prescribed outside diameter. This is a delicate job and one that requires considerable skill in handling the lathe.

11-21. After the commutator has been machined to the diameter prescribed by the overhaul manual for that specific generator, the mica that is between the segments must be undercut. This work may be done by a machinist. As the brushes wear away during the service life of the generator, the cabron dust may settle momentarily into the spaces between the commutator segments; and as the armature rotates, most of this dust is thrown out of the slots due to centrifugal force. If oil or grease should get on the surface of the commutator, it might mix with the carbon dust and cause it to collect and stick in the slots between segments. If this condition did occur, the carbon dust particles might adhere to the walls of the slots so that eventually a short circuit would develop between the various commutator segments. This short-circuited condition would

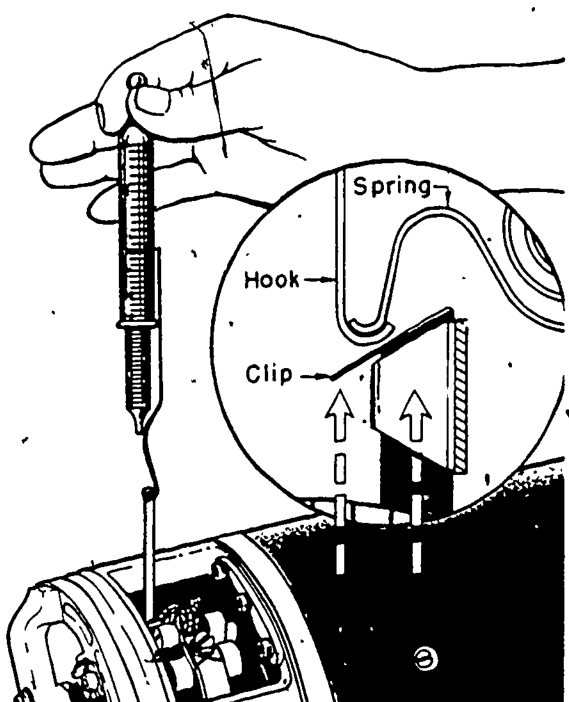

Figure 26. Checking brush springs.

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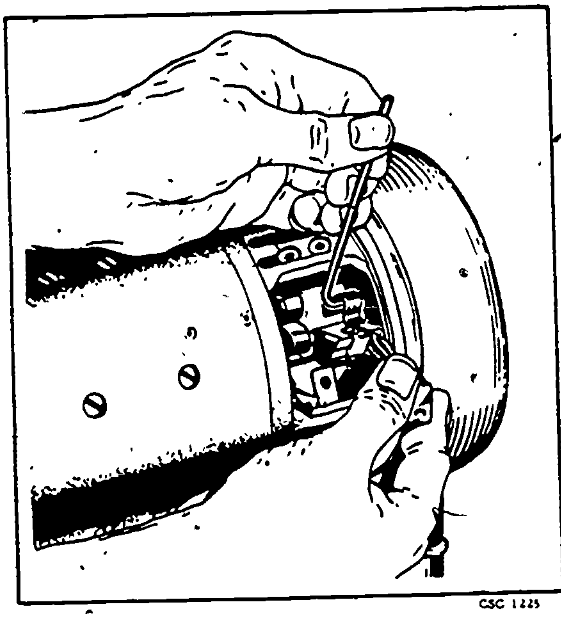


Figure 27. Removing brushes.

cause the output voltage of the generator to be adversely affected.

11-22. You are familiar with the color of a new copper penny, and that is what you may expect the copper commutator to look like at all times. However, this is not correct. Due to the oxidation of the copper and operation in contact with the carbon brushes, the color of a normally operating commutator is a chocolate brown. Any burnt spots along the side of the commutator segment indicate that some brushes are not properly fitted to the commutator or that trouble is about to develop. You may remove burned spots by placing a strip of sandpaper the width of the commutator, with the sanded side down, around the commutator, and sliding it back and forth. Take care not to work so long on a burned spot as to cause the surface to develop a flat spot. After you complete the operation, direct an airstream through the brush assembly to remove any loose abrasive or carbon dust.

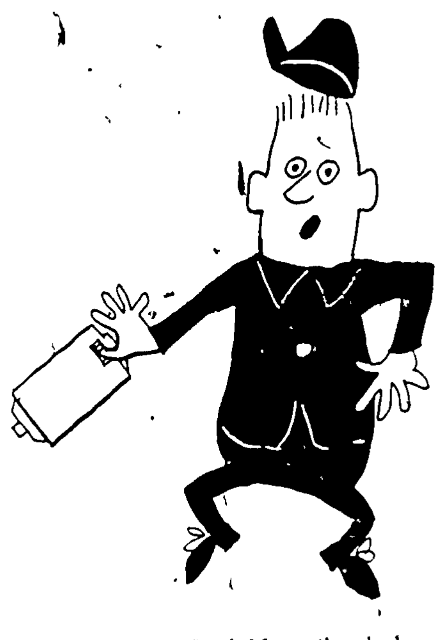
11-23. *Brushes.* A spring device holds each brush in contact with the commutator. You should check the brush spring pressure periodically in accordance with instructions contained in the applicable TO on the generator. Figure 26 shows you how to check the tension, using a small spring scale normally included in your electrician service tools. The proper time to read the scale is when the spring lever is about one-sixteenth of an inch off the brush. You will have to make certain of the exact spring pressure for each particular generator from the pertinent technical order. Too much spring pressure increases the friction between the brushes and the commutator, and consequently, increases the wear on the brushes, whereas too little contact pressure may lead to jumping brushes with poor output and the possibility of burning and damaging the commutator.

11-24. When you lift the brush springs to remove the brushes for inspection, use a small hook made from a piece of wire instead of your finger (see fig. 27). This prevents the possibility of the spring slipping from your grasp and slamming down against the brush, which could cause the brush to crack, chip, or otherwise be made unfit for further use.

11-25. As you remove each brush from its holder, examine it carefully for cleanliness and length. Examine the contact face for correct seating on the commutator. If the brushes or the brush holders need cleaning, wipe them with a cloth moistened with an approved cleaning solvent. Never immerse carbon brushes in cleaning solvent.

11-26. The length of the new brushes varies from manufacturer to manufacturer; so does the method of measuring the length of the generator brushes. There are as many different minimum lengths of brushes as there are generators, so you must look in technical orders for the minimum length for a particular generator. After some experience, you learn approximately how much the brushes wear between inspections, and then you are prepared to change the brushes before they reach their minimum lengths.

11-27. The correct seating of the brushes on the commutator is very important, and you can



Cartoon 4. Look Ma no thumb.

readily check this, by looking at the contact face of the brush. Properly seated brushes should show contact 100 percent across the brush thickness for at least 70 percent of the brush width, as shown in figure 28, item A. In figure 28 the solid black areas represent noncontact areas, and the portion of the brush contact face that is shown with light lines, represents the area of the brush that is in contact with the commutator. Figure 28, item B, shows the end view of a new brush which must be seated to the commutator after installation. Figure 28, item C, shows a brush that is showing 100 percent contact across both the thickness and the width of the brush, which is a highly desirable condition. Items D and E of figure 28 show brushes that are making 100 percent contact across the brush thickness for at least 70 percent of the brush width. Items F and G of figure 28 depict conditions which are not acceptable because the brushes are not making 100 percent contact across the thickness of the brush.

11-28. When new brushes are installed in a generator at a factory or depot, they are allowed to run for up to 1 hour at no load and in this way, wear in by themselves. This cannot and should not be done on generators that are installed on aircraft, for the brushes may be called

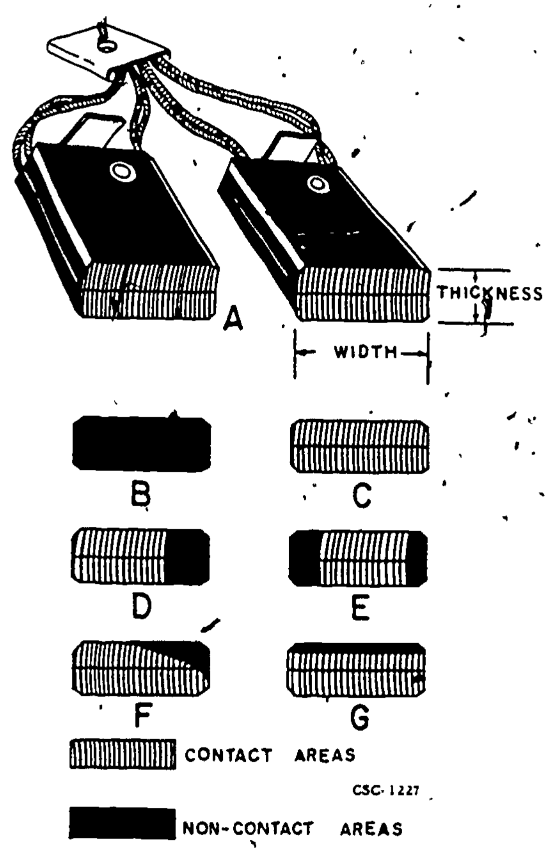


Figure 28. Correct and incorrect brush fits.

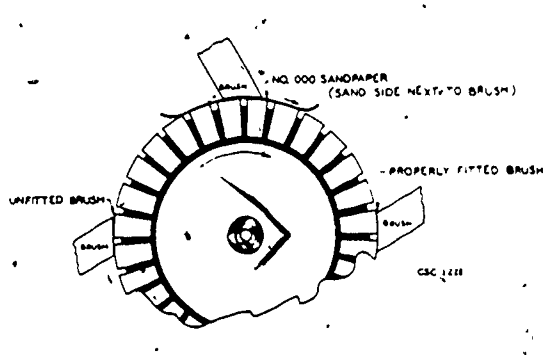


Figure 29. Seating brushes with sandpaper.

upon to conduct current as soon as the generators start turning. Unless the brushes are properly making contact with the commutator, serious arcing might occur which could damage the commutator.

11-29. Figure 29 shows how a new unfitted brush appears as it rides on the surface of the commutator, and directly opposite, how a properly fitted brush appears. To achieve this effect, when you install new brushes, place a strip of Nr. 000 or Nr. 0000 sandpaper, the width of the commutator, under the brush with the sanded side next to the brush, and then withdraw it from under the brush in the normal direction of rotation of the armature. Do not use emery paper or crocus cloth for this operation, for they are metallic materials and should particles of the material become imbedded in the brush, arcing and pitting of the commutator will result. Do not slide the sandpaper back and forth under the brush. After you have withdrawn the sandpaper, lift the brush from the commutator and reinsert the sandpaper under the brush. As the brush is again held against it, withdraw the sandpaper in the normal direction of rotation. Continue this process until the brush fit meets the minimum requirement of 100 percent contact of the brush thickness for at least 70 percent of the width of the brush. After you have completed this procedure, normal generator operation will complete the operation of fitting the brushes to the commutator.

11-30. *Armature tests.* The first of the three electrical tests for the armature is the check for grounds. On all of the conductors used in the armature, the only insulation used is a baked coating of insulating varnish. If this insulating varnish should chip or otherwise be worn away, there is a possibility that one or more of the armature conductors may be touching some part of the iron core of the armature. This test is also a check of the insulating value of the mica between the commutator segments and the main body of iron of the armature assembly. This

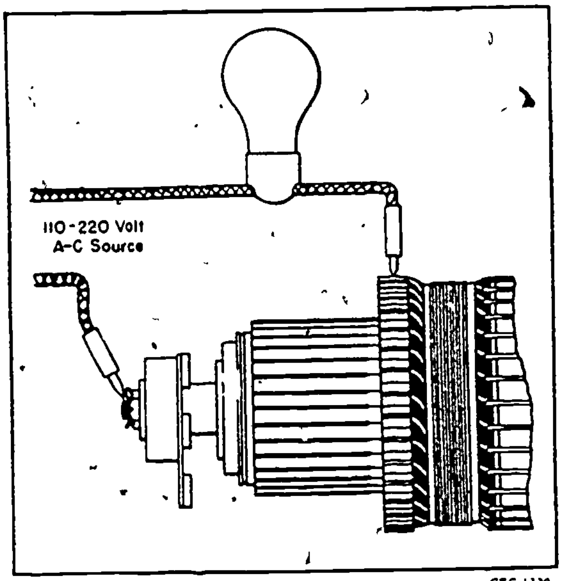


Figure 30. Checking armature assembly for grounds.

check is called a high-potential test, in that a 110-volt or a 220-volt ac test lamp is used. Place one of the test lamp leads on the armature shaft (see fig. 30) and the other lead on the commutator 'riser.' Now move the lead that is touching the commutator back and forth to make contact with several segments. If the test lamp lights, there is a ground, and the armature assembly must be discarded. Because of the method used in winding armatures, you do not necessarily have to perform this check around the full circumference of the commutator; for if any one conductor of the armature winding is grounded, a circuit will be completed for the test lamp.

11-31. The second check is the growler, or the short-circuit check. The typical growler (see fig. 31) consists of a laminated U-shaped soft iron core with the open ends upward and an electrical winding that is normally inclosed within the base of the unit. A growler operates only when connected to a source of alternating current. The unit is so constructed that when an armature is placed within the open ends of the electromagnet, a vibration is caused between the armature core and the growler poles, which results in a buzzing or a growling noise. This noise is no indication of the general condition of the armature, for every armature, good or bad, will have the growling sound when placed on the unit with the electrical circuit completed.

11-32. The combination of an armature and a growler is similar to a transformer; the core of the armature in contact with the pole pieces of the growler forms an all-metal path for the magnetic circuit. The winding of the growler becomes the primary of the transformer, and the winding of the armature becomes the secondary, in which a voltage is induced by the alternating action of the magnetic field developed in the iron core.

11-33. To check an armature for short circuits (see fig. 31), hold a piece of a broken hacksaw blade loosely on the top of the armature and slowly move it all the way around the armature, turning the armature assembly on the growler as required. Normally there is a voltage developed in the windings of the armature, but because of its construction, no current will be flowing within the armature. If the hacksaw blade should be attracted to the armature at any point and buzzes, it indicates that there is a current flowing in the conductors that are beneath the blade, and therefore a short circuit must exist within the armature. If there is a short circuit, the armature assembly must be discarded, unless the trouble is due to solder that is briding between commutator risers. This trouble is usually reparable.

11-34. You can safely perform the third and final check on armatures only after the previous two tests have revealed no troubles. The check for open circuits in an armature can be made in two ways; (1) with the ac ammeter on the growler, and (2) with a hacksaw blade.

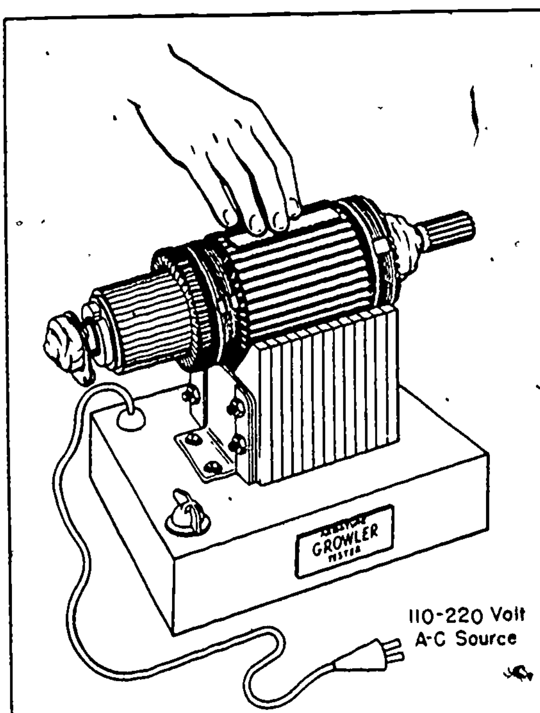
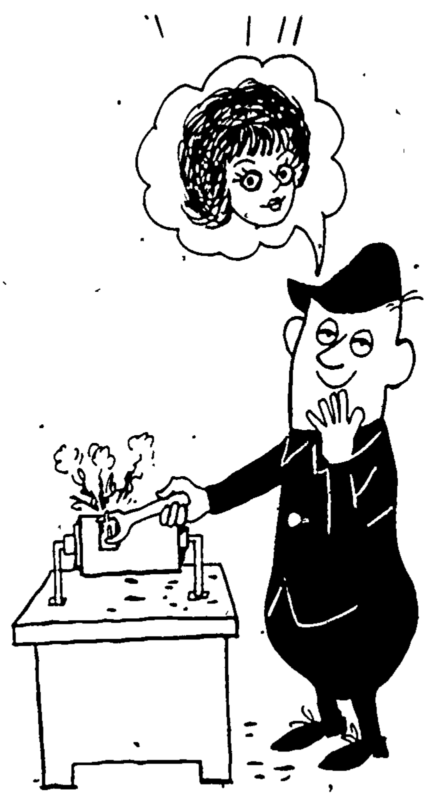


Figure 31. Checking armature assembly for short circuits.



Cartoon 5. Oh! What a beautiful doooooll.

11-35. To check the armature for open circuits with the ammeter on the growler, place the armature on the growler and turn it on. Adjust the contact fingers until they touch the adjacent segments on the commutator. Rotate the armature and continue the test by placing the contact fingers on each succeeding pair of segments. The ammeter will register zero if the armature contains an open winding when the contact fingers are placed on the segments connected to that winding. If the armature is functional the ammeter will register a value as specified in the TO for the generator armature being tested.

11-36. To check the armature for open circuits with a hacksaw blade, place the armature on the growler and turn it on. Short circuit each segment of the commutator with the adjacent segment using the saw blade as the armature is rotated. A strong flash or spark should be obtained between each pair of adjacent segments if there are no open coils in the armature. If no spark is seen, the armature has an open coil.

11-37. If no reading on the ammeter is obtained or no spark at the commutator is seen, check the connections at the commutator riser for security. If the trouble is not at the soldered connection to the riser, the armature should be discarded.

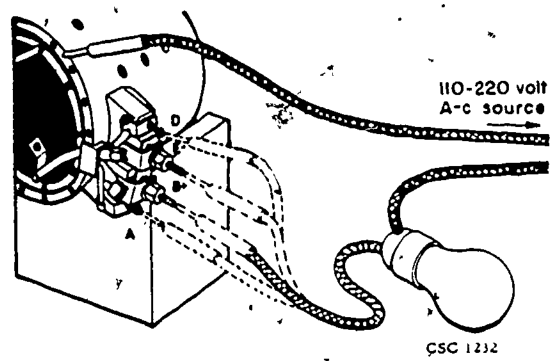


Figure 32. Checking field assembly for grounds.

11-38. *Field tests.* First, give the field assembly a high-potential test, using either a 110-volt or a 220-volt test lamp. (See fig. 32.) Place one test lamp lead on an unpainted part of the generator frame; then, touch the other lead to each of the terminals A, B, D, and E. The identification of all aircraft generator terminals is standardized. The terminals are identified by the letters A, B, D, and E, both for simplicity and standardization. Terminal A is always the shunt field terminal, terminal B is always the generator positive terminal, terminal D is always the generator equilizer terminals (to be discussed later), and terminal E is always the generator negative terminal. If the lamp lights, there is a ground in the circuit and the field assembly must be discarded, unless the trouble is at the generator terminals and is reparable.

11-39. Next, check the shunt field circuit resistance with an ohmmeter. (See fig. 33.) To do this, connect one ohmmeter lead to the E terminal and the other to the A terminal, as shown in figure 33. The shunt field resistance varies from generator model to model and between manufacturers. Therefore, you must obtain specific information for a particular generator from the applicable technical order. A resistance lower than

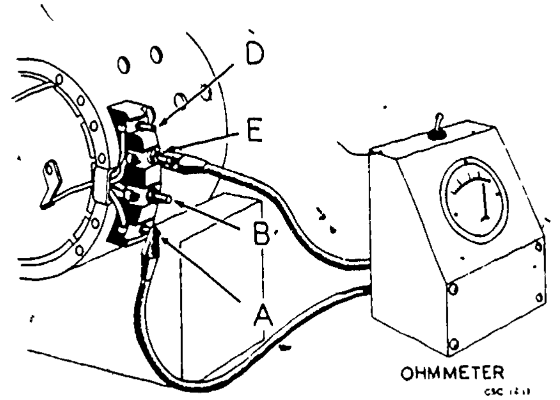


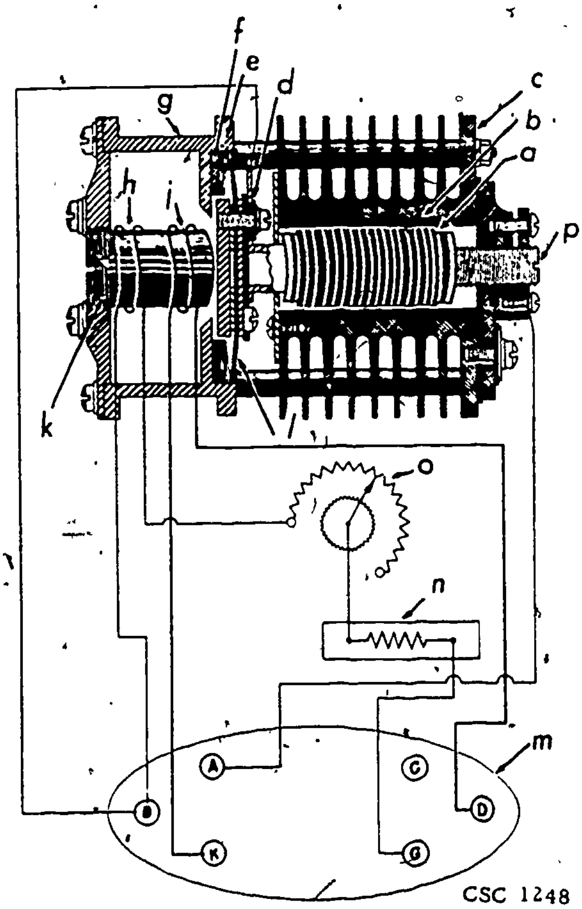
Figure 33. Shunt field resistance check.

the minimum specified may indicate a short circuit in the shunt field, and a resistance higher than the maximum allowable may indicate an open circuit or a loose connection. If the resistance is too low or too high, you must discard the field assembly, unless you can easily find the trouble and can repair it.

12. DC Generator System Components

12-1. Now that you are familiar with the characteristics of dc generators, it is only natural that the next topic should be that of the various control and protective devices that are in all dc generator systems.

12-2. For many reasons, you must be familiar with the operation and characteristics of these components. For example, when troubleshooting dc generator systems, you must know how the various components function so that you can distinguish between troubles caused by the generator, and those that are caused by the voltage regulator or other controlling devices. Another reason for learning about these components is that you are required to overhaul or repair many of them. Further, after you have performed the necessary maintenance on these components, you will have to bench test and calibrate them for proper operation.



A. CARBON STACK
B. INSULATING TUBE
C. CARBON-PILE HOUSING
D. ARMATURE ASSEMBLY
E. COMPENSATING RING
F. SPACER
G. SOLENOID HOUSING
H. VOLTAGE COIL
I. EQUALIZING COIL
K. ADJUSTABLE CORE
L. SPRINGS
M. BASE PLATE
N. FIXED RESISTOR
O. VARIABLE RESISTANCE
P. ADJUSTING SCREW

Figure 34. Schematic of carbon-pile voltage regulator.

12-3. Most of the electrical equipment installed in an aircraft is designed to operate normally within a specified range of voltages; variations from these limits cause an undesired change in the characteristics of the equipment. If for some reason the generator were to produce an excessively high voltage, much of the equipment in operation at that time could burn out. To prevent this from occurring, various control and protective devices are incorporated into the generator circuits. These devices disconnect the generator from the distribution system whenever the output voltage rises above or below a predetermined value. The output of all dc generators used in aircraft today is approximately 28 volts. The amperage capacity varies from generator to generator, but the output even under full load is always approximately 28-volts dc.

12-4. **Voltage Regulators.** The purpose of the voltage regulator in a generator system is to maintain a constant output voltage under varying load conditions. Of the many factors that determine the output voltage of a generator, the only one that is readily controllable is the magnetic field strength of the field. The voltage regulator, then, controls the output of the generator by controlling the current through the field coils, and consequently, the strength of the field. Although there are many ways in which this can be done, the most common method is to use a carbon-pile type voltage regulator to control the current in the field coils.

12-5. *Carbon-pile voltage regulator.* In your work as an aircraft electrician, you have no doubt had many occasions to repair or adjust a carbon-pile regulator. Nevertheless, to refresh your memory, let's start the discussion with a brief review of this voltage regulator.

12-6. As you know, carbon is a conductor of electricity. It is far from being a perfect conductor, but it has several electrical characteristics that warrant its use. First, the more mechanical pressure (compression) applied to a number of carbon units in contact with each other, the less is the resistance of the group. As carbon units are compressed, their resistance decreases; and conversely, as the mechanical pressure exerted upon the assembly is relieved, their resistance in-

creases. The carbon particles are always in contact with one another, with the resistance-determining factor being the amount of compressive force exerted upon them. The second all-important characteristic is that the effect of increased temperature upon carbon is the exact opposite from the reaction of the other types of conductors previously discussed in this course. As the temperature of copper, silver, and aluminum increases, the resistance of these metals goes up also. But, with carbon, as the temperature increases, the resistance decreases.

12-7. The carbon-pile regulators presently used in aircraft are manufactured by many companies and may vary slightly in external appearance, but mechanically and electrically they operate alike. A detailed construction and wiring diagram is shown in figure 34. In this type of regulator, carbon discs (a) are placed in an insulating ceramic tube (b) inside of the carbon-pile housing (c), which is fitted with fins to radiate the heat produced as the current flows through the resistance of the stack. An electromagnet, consisting of a voltage coil (h) and an adjustable core (k), is located within the solenoid housing (g) at one end of the carbon stack. An insulated plate and adjustable screw (p), which makes contact with the carbon pile, is mounted on the other end of the carbon-pile housing. The other contact with the carbon pile is made through the armature assembly (d). When the generator is producing a voltage below that which the regulator has been adjusted to maintain, the springs (l) exert a mechanical pressure upon the discs, lowering the stack resistance to a lesser value. This allows more current to flow through the field coils. Located under the springs is a spacer (f), which is installed by the manufacturer or overhaul activity, so as to place the armature in the proper position. Because the resistance of the carbon stack varies inversely with the temperature, to prevent any change in surrounding air temperature from affecting the setting of the regulator, a bimetallic compensating ring (e) is situated on top of the spacer and under the tip of the springs (l) which are exerting mechanical pressure on the carbon stack. As the temperature of the surrounding air increases, the compensating ring tends to flatten out and by so doing, decreases the mechanical pressure exerted upon the stack. The resulting decrease in mechanical pressure on the carbon stack increases the resistance of the stack sufficiently to compensate for the decrease in resistance resulting from the increased surrounding air temperature.

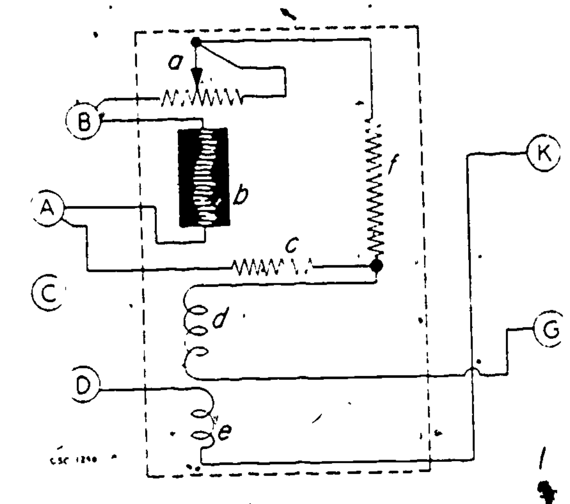
12-8. The electrical circuits of the regulator are all brought out from the base plate (m) through which the circuits are automatically completed when the regulator is installed in the standard Air Force voltage regulator base. Changes in the voltage of the generator are applied to the voltage coil (h) through terminal B of the base plate, the variable resistor, the fixed resistor, and to ground through terminal G of the base plate. The electromagnet works in opposition to the springs that tend to compress the carbon stack. Therefore, as the voltage of the circuit increases, the current flow through the voltage coil increases and exerts more attraction for the armature. Any movement of the armature, however slight, toward the core of the electromagnet tends to increase the resistance of the stack of carbon discs. The field current of the generator has to flow through the carbon stack from one end to the other, and thus current flow through the field coils is controlled by the output voltage of the generator.

12-9. The fixed resistor (n) in the electromagnetic circuit is for the purpose of limiting the current flow in the control circuit to a low value, while the variable resistance (o) provides a means of varying the resistance in the control circuit, and in this manner determines the voltage which the regulator will maintain.

12-10. A glance at figure 34 shows that there is one more coil in the electrical circuit which hasn't been mentioned before, and that is the equalizer (i), which is connected between terminals D and K of the base plate. The equalizer circuit is wired into the circuit only in installations where two or more generators are being operated in parallel to supply the electrical load. We will discuss the equalizer circuit later in this volume.

12-11. The only adjustment authorized on a voltage regulator outside of depot activities or maintenance shops is the variable resistor. Turning this adjustment from one end of its travel to the other should provide a voltage range of from 26 to 30 volts when the generator is operating within its normal speed range and the regulator is performing normally. Any time that the voltage regulator does not automatically control the voltage within ±0.25 volt of its setting throughout the full-load capacity of the generator, the carbon discs are wearing or the regulator is internally out of adjustment.

12-12. Many modern voltage regulators replace the variable rheostat with a potentiometer, which is used as both a control and protective circuit. Figure 35 shows a schematic of a carbon-pile regulator with a potentiometer. Note also that a stabilizing resistor, c, has been added. If the moving contact burns off or is otherwise damaged, current continues to flow in the volt-



A. POTENTIOMETER
B. CARBON PILE
C. STABILIZING RESISTOR
D. VOLTAGE COIL
E. EQUALIZING-RESISTOR
F. FIXED RESISTOR

Figure 35. Carbon-pile regulator with stabilizing resistor.

age coil circuit, but now it must flow through the full resistance of the potentiometer. Because of the added resistance in the control circuit, the output voltage is higher than normal. However, current is flowing in the voltage coil circuit, preventing the carbon stack from going to a minimum resistance condition. This prevents the output voltage from reaching its maximum value, reducing the possibility of damage to the generator or of having an electrical fire.

12-13. The purpose of the stabilizing resistor circuit is to prevent the arcing which formerly occurred between the discs of the carbon pile. If all the load is removed suddenly, the voltage output of the generator rises above normal for a brief instant. This high voltage being impressed upon the voltage control circuits causes a higher than normal current flow through the voltage coil. The resultant movement of the armature assembly of the regulator is abrupt and may cause the discs to separate completely. When this occurs, the magnetic field surrounding the field coils collapses and induces a voltage in the coils (self-induction). This voltage tends to continue the flow of current in the same direction and to produce an arc between the discs. By having the stabilizing resistor in the circuit, another path is provided for this current in the event that the discs separate; thus the arcing tendency is eliminated. This improvement greatly reduces damage to the carbon pile and lengthens the service life of the regulator.

12-14. *Inspections.* Normal operation of the voltage regulator is accompanied by the radiation of large amounts of heat from the regulator to the surrounding air. You must take care to insure that no item of your clothing or other material is placed over the voltage regulator. This would restrict the free circulation of air over the regulator and cause the operating temperature of the carbon pile to increase. Previously, it was mentioned that as the temperature of the carbon increases, its physical resistance is decreased. For this reason, if the free circulation of air about the voltage regulator is restricted, the voltage of the system tends to rise above its normal level.

12-15. While you are inspecting voltage regulators, always look under the regulator mounting base and remove any loose nuts, bolts, or scraps or wire that might be found there. Then, check the shock mounts by which the regulator mounting base is fastened to the aircraft structure for any evidence of damage. If it is necessary for you to remove the regulator from the base, make certain the generator is not running at the time; otherwise, dangerous arcing occurs or the contacts on the voltage regulator base become damaged. When you are checking the operation of the voltage regulator, you must use a precision voltmeter. Allow the regulator to operate for at least 15 minutes so that it reaches the proper operating temperature.

12-16. When you are checking and adjusting the voltage regulator, the positive lead of the precision voltage meter is connected to B terminal of the voltage regulator mounting base (with the voltage regulator mounted), and the negative lead to ground. When the regulator warmup period is completed and the engine is operating at a speed established by the applicable TO, the voltmeter should read 28 volts and should maintain that reading as an electrical load is applied and removed from the generator. There should be only slight surges in voltage when large electrical loads are applied to or removed from the generator.

12-17. **Generator Control Units.** The earliest type of generator control unit was simply a cutout consisting of two coils. One coil became energized when the generator output reached a certain value and connected the generator to the load. The other coil became energized when the generator output became higher than normal and disconnected the generator from the load. As generator systems became more sophisticated, it became necessary to use controls of a more advanced type.

12-18. *Reverse-current relays.* With the advent of the generator voltage regulators that plugged into a standard voltage regulator mounting base, there appeared an advanced type of cutout known as a reverse-current relay. Reverse-current relays (RCR's) are manufactured by sev-

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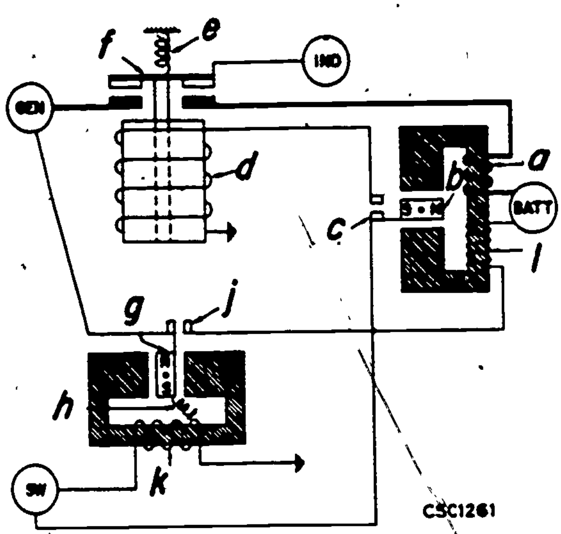

A. SERIES COIL
B. DIFFERENTIAL RELAY ARMATURE
C. DIFFERENTIAL RELAY CONTACTS
D. CONTACTOR COIL
E. CONTACTOR RETAINING SPRING
F. CONTACTOR
G. VOLTAGE RELAY ARMATURE
H. VOLTAGE RELAY CALIBRATION SPRING
J. VOLTAGE RELAY CONTACTS
K. VOLTAGE COIL
L. DIFFERENTIAL COIL

Figure 36. Internal circuits of differential voltage reverse-current relay.

eral different companies, and some companies produce many different models, of which only one will be illustrated and explained here. This model is generally referred to as a differential voltage reverse-current relay.

12-19. The differential voltage-current relays serve the following four main functions: (1) to close the circuit between the generator and the power distribution system when the generator voltage is greater than the bus voltage, (2) to open the circuit between the generator and the distribution system whenever the bus voltage exceeds the generator voltage, (3) to keep the circuit open between the generator and the power system in the event of reversed polarity of the generator, and (4) to act as a remotely controlled switch. It is referred to as a differential relay because it operates on the difference between generator and bus voltage, rather than as a fixed relay that operates only when the generator voltage reaches a specific value. The basic unit is composed of three relays inside of one case, the wiring of which is shown schematically in figure 36. The relays are designated as follows: voltage relay, differential relay, and contactor relay.

12-20. For the RCR to close the circuit from the generator to the bus, the generator switch must be in the closed position. (Refer to fig. 36.) When the generator potential reaches a point between 20 and 24 volts, the current flowing through the voltage relay coil (k) creates a magnetic field that causes the voltage relay contacts (j) to close. This voltage must be of the correct polarity or the permanent magnet armature will not operate. With the closing of the voltage relay contacts, a circuit is completed from the GEN terminal to the BAT terminal by way of the differential coil (l). This is not the main current path through the relay. With a potential on the GEN terminal that is between 0.35 and 0.65 volt higher than that at the BAT terminal, enough current flows through the differential coil to displace the permanent magnetic armature and close the differential relay contacts (c). The contactor coil is in this manner now connected to the SW terminal, from which point the circuit is completed back to the voltage source (the generator). The 20 or 24 volts of the generator applied at the SW terminal causes the main contactor coil to operate the movable core, closing the main contactor points. This completes the load-carrying circuit.

12-21. The main contactor points complete a circuit between the BAT and GEN terminals. When the generator potential is lower than the battery voltage, current ordinarily flows from the battery to the generator, rapidly draining the battery. When the flow of reverse current reaches a predetermined point between 16 and 25 amperes, it overpowers the magnetic effect of the differential coil and reverses the polarity of the differential relay electromagnet. This reversal of polarity causes the differential relay contacts to open, and thus, opens the contactor coil circuit. The spring-loaded main contactor points then open and interrupt the reverse flow of current through the generator.

12-22. *Overvoltage relay.* In any generator system there is always the possibility of excessive voltages due to certain circuit malfunctions. If this should occur, the overvoltage condition is sensed by the overvoltage relay, which sends a trip signal to the field control relay. The field control relay then isolates the faulty generator.

12-23. A typical schematic diagram of the overvoltage relay is shown in figure 37. Sensing power is applied to terminal S of the relay. If the generator output voltage exceeds a certain value, the sensing power is strong enough to energize the relay through the ground at terminal G. When the relay coil is energized, a circuit is completed through contacts P and T. Terminal P is connected to the aircraft bus, and terminal T is connected to the trip coil of the M-2 field control relay. Completing the circuit from P to T effectively disconnects the generator from the distribution system under overvoltage conditions.

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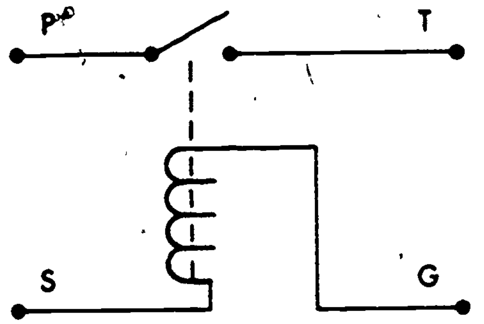
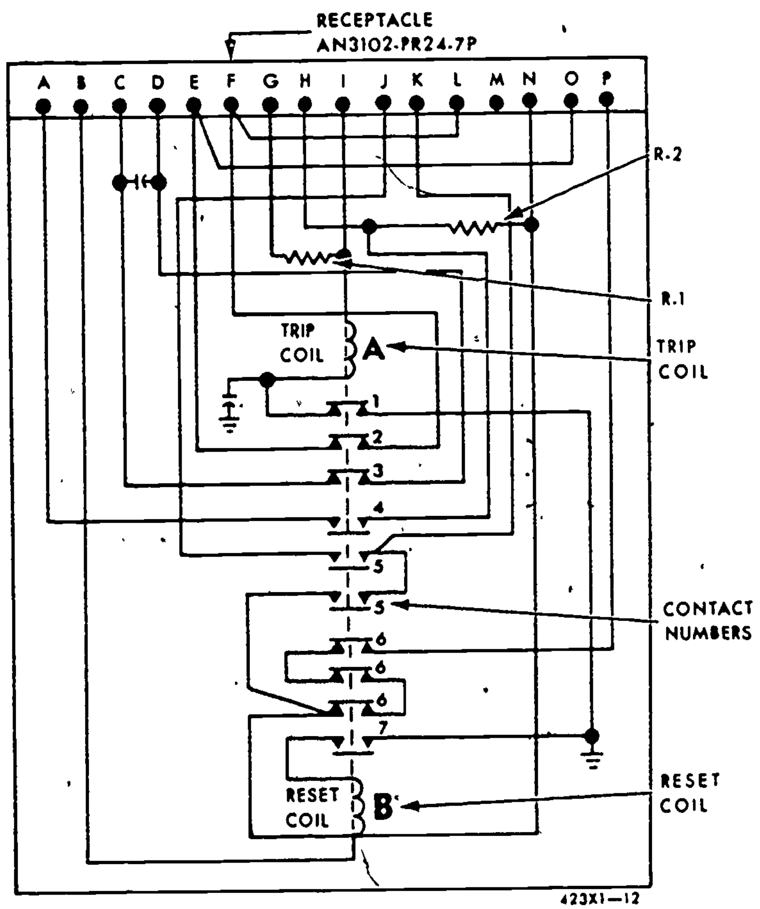


Figure 37. Overvoltage relay schematic.

12-24. *Field control relay*. The overvoltage relay just discussed protects all electrically operated equipment from damage caused by excessively high voltages. A field control relay is used to protect the generator and its associated wiring. A schematic of a typical field control relay, type M–2, is shown in figure 38. There are two relays inside the housing, the trip relay (A) and the reset relay (B), and ten sets of electrical contacts, six of which are normally closed and the remaining four normally open when the generator system is operating normally. The relays used in this unit are latch type units, meaning that once a relay is energized and the contacts moved to a certain position, the contacts are mechanically held in that new position until the other relay coil is energized.

12-25. The two relays actually work against each other, the trip relay moving the normally closed contacts to an open position and the normally open contacts to the closed position, while the reset relay reverses the contact positions again. The resistor R–1 is connected into the circuit to prevent damage to the trip coil that might otherwise be caused by an overvoltage condition; therefore, the resistor is connected in series with the trip coil. The second resistor, R–2 is connected between terminal H, which is connected directly to the bus bar, and terminal N, which is connected to the shunt field terminal of the generator. This resistor is installed for the express purpose of keeping a positive voltage applied to



RELAYS SHOWN IN RESET POSITION

Figure 38. Field control relay schematic.

the field terminal of the generator at all times. The ground circuit of each of the two relays is completed through a set of contacts (1 and 7), which open after the corresponding relay has been actuated. Since the contacts are mechanically latched into position after the operation of a relay, there is no need to continue to energize the relay coil; consequently, these contacts are provided to open the circuit after the relays are actuated.

12-26. The field circuit between A terminal of the voltage regulator and A terminal of the generator is completed through three sets of contacts (6) that are connected in series. The principal reason for having three sets of contacts in series is to make sure that the circuit will open. The warning light is wired through the normally open contact (4). When the generator system is operating normally, the light is out because this circuit is open; but any time that the field control relay has been actuated, the light comes on to tell the pilot or engineer that the generator is not performing normally. The wire which runs between the pilot's or engineer's control switch and the SW terminal of the reverse-current relay is controlled by a set of normally closed contacts (3) so that the reverse-current relay is also automatically disconnected in the event of circuit troubles.

12-27. Another circuit that may also be wired through the field control relay is the equalizer circuit in those installations where two or more generators are operating in parallel to supply the electrical load. This concludes the discussion of generator control and protective devices. Next, you will learn how all of these units are connected into typical generator systems.

13. DC Generator System Operation

13-1. So far in this course you have learned about the various types of generators used in aircraft electrical systems. You have also learned the purpose of the control and protective devices used in dc generator systems. Now it is time to learn how all these components fit together to form a complete operating system.

13-2. Why is this important to you? First, you must know how a system operates under normal conditions before you can troubleshoot that system. Second, it is not enough to know that a generator system contains certain components. You must know how these components are interrelated and what effect they have on each other. Another factor you should consider is that many aircraft have more than one generator in the dc system. When you are required to perform maintenance on these systems, you must know the requirements for paralleling, as well as the actual paralleling procedure you should follow.

13-3. A generator control system provides both control and protection for the dc generator throughout its operating range, from no load to full load. With this in mind, let's discuss the single-generator system and see how control and protection are provided.

13-4. **Single-Generator Control System.** The single-generator control system regulates, controls, and protects the generator. You may find the essential units—reverse-current relay, field control relay, overvoltage relay, and the voltage regulator—at various locations on the aircraft or as parts of an elaborate control system contained in a single box mounted on an assembly rack, and called a generator-control panel. Both systems provide the necessary control and protection.

13-5. Figure 39 shows a typical single-generator control system with all the necessary control system components. The system also contains an ammeter, a failure light, and a voltmeter, all of which provide the crew with a means of monitoring the system.

13-6. The voltmeter is shown connected directly to one side of the generator switch, but in some installations it may be connected directly to the GEN terminal of the reverse-current relay. This voltmeter is a general reference instrument and should never be used when making adjustments of the system voltage. The generator switch provides the pilot with manual control over the generator system.

13-7. *Initial power.* For the generator system shown in figure 39, when the battery switch is closed (ON position), 28 volts dc from the bus will be applied to H on the M–2 relay, P on the E–2 relay, and terminal 2 on the generator switch. The necessary initial power is now applied to the generator control system. The purpose of this initial power is to provide trip power in the event of an overvoltage condition, and apply a positive dc potential to the generator field.

13-8. *Reverse-current relay.* As the engine starts and the generator comes up to speed, generator output is applied to the GEN terminal of the RCR. The generator output could be residual or its rated output, 28 volts dc. If the field circuit is complete (M–2 relay closed) and the generator switch is on, the generator output is 28 volts dc, and the generator is automatically connected to the aircraft bus through the reverse-current relay (RCR).

13-9. After the generator is connected to the bus, suppose its output voltage should drop below battery voltage; current would then flow from

the battery to the generator. This reverse current could damage the generator windings. Under these conditions the generator would be removed from the bus. This reversal of polarity causes the differential relay contacts to open, and thus open the contactor coil circuit. The spring-loaded main contactor points would then open and interrupt the reverse flow of current through the generator.

13-10. *Field circuit.* Generator output voltage is maintained constant throughout its operating range by the voltage regulator (VR). Figure 39

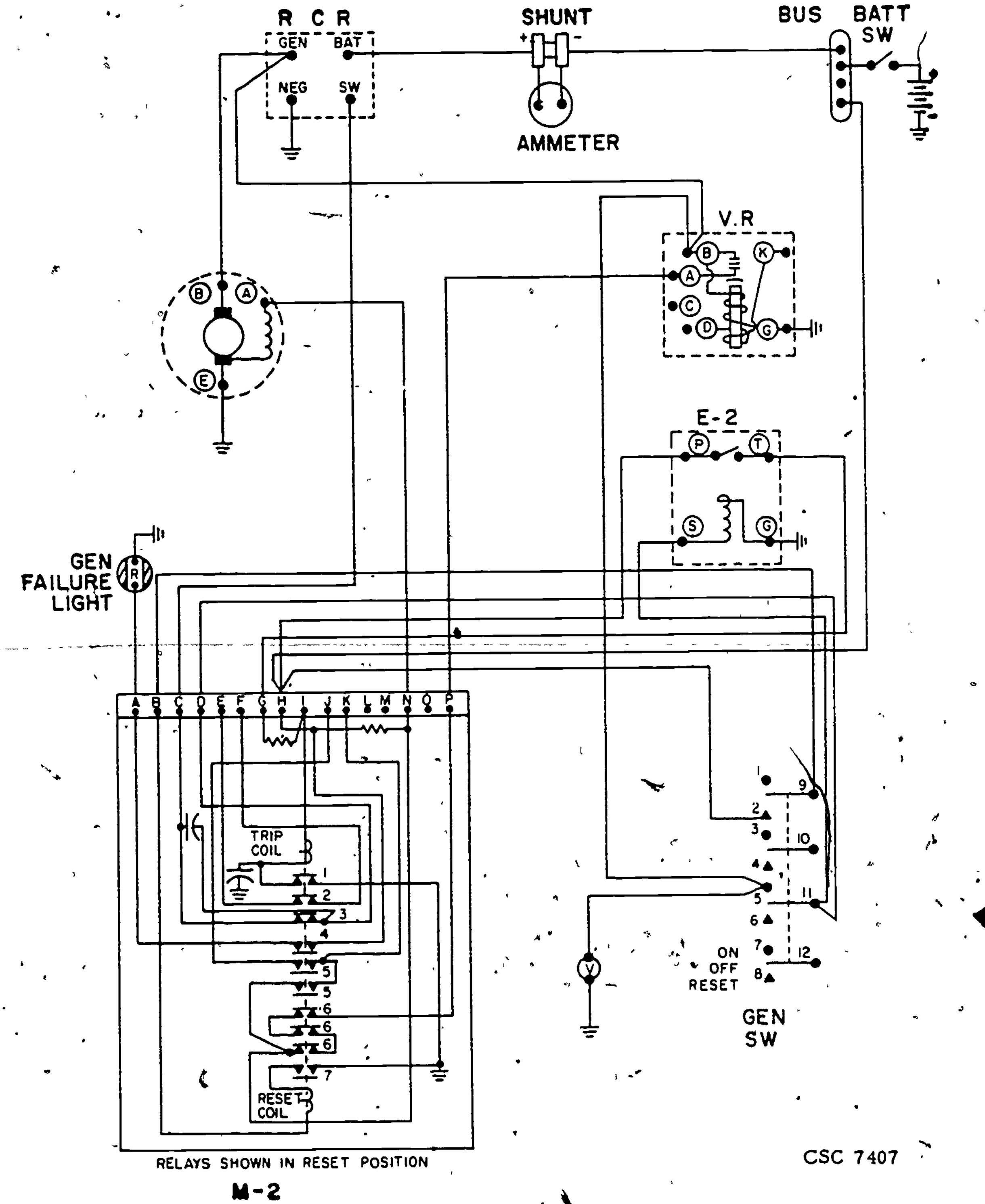


Figure 39. Single generator system.

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shows how the field circuit is powered from the GEN terminal of the RCR to the voltage fegulator (VR) through the carbon stack, then on through the field control relay (M–2) to the A terminal on the generator. The current flow in the field circuit is controlled by the carbon stack. Any change in speed or load will affect the carbon stack resistance and in turn the generator output voltage.

13-11. *M–2 field control relay.* The generator field circuit is routed through the M–2 relay between terminals P and N. Any time an overvoltage condition exists, the E–2 overvoltage relay will trip the M–2 relay and open the field and switch circuits. This will cause the generator voltage to drop to residual, and the RCR will remove the generator from the aircraft bus. The M–2 relay will also cause the generator failure light to glow. The M–2 relay can be reset by the generator switch or manually be a reset button on the relay itself. (See fig. 39.)

13-12. *E–2 overvoltage relay.* This relay senses the generator output voltage. Figure 39 shows the sensing circuit connected from S terminal of E–2, through the ON position of the GEN switch, to the B terminal of the voltage regulator (VR). Thus, you find that the E–2 relay is always connected to the output of the generator. If the generator output voltage increases to a predetermined value (approximately 32.5 volts) due to some circuit fault, the contacts between P and T (E–2 relay) close. When these contacts close, 28 volts from the aircraft bus is applied to G on the M–2 relay,. and the M–2 relay trips. The generator is removed from the aircraft bus in the same manner as previously described.

13-13. This completes the discussion of the single-generator control system. You should be familiar enough with the circuitry of the single-generator control system to troubleshoot the system. We will cover this operation later in another section of this volume. To be sure that you know and understand the single-generator control system, trace the operation of each component once more on figure 39.

13-14. **Multi-Generator Control System.** This system performs the same functions as the single-engine control system. Except for one feature, it is a duplication of the single-generator control system. Each multi-generator control system has an equalizer circuit. This circuit parallels the generators; it insures that each generator will carry its share of the load. This is called equalizing the amperage output of each generator in relation to the current output of the other generators connected to the power bus when a dc load is applied.

13-15. *Parallel operation.* When two or more generators are operated at the same time to furnish current, it is necessary that each generator furnish an equal part of the total load. As long as all the generators are operating, there is no sense in having one doing all the work and the others loafing on the job; then, too, by distributing the load equally, the wear is divided among the generators.

13-16. When two generators, as shown in figure 40, are supplying equal amounts of current to the load, the currents through the equalizing resistors (j) are equal, and the voltage drop across both equalizing resistors is the same; therefore, the potential at both generator D terminals is the same. This represents the ideal operating condition. When the current outputs from the generators become unequal, a difference in potential exists at the D terminals. Remember that a current flows any time there is a difference in potential and a complete electrical circuit between the points. This small difference in voltage is responsible for the operation of the equalizer circuit.

13-17. All voltage regulators have an equalizer coil wound around the magnetic core of the voltage coil. The equalizer coil consists of a comparatively few turns of small wire, the ends of which are connected to the D and K terminals of the regulator subbase, as shown in figure 40. Since current may flow through the equalizer coil (F) in either direction, the polarity produced by the equalizer coil depends on the direction of current flow. When current flows in one direction through this coil, the polarity of the equalizer coil opposes the polarity produced by current flow through the voltage coil, thereby reducing the magnetic strength of the coil core. This reduction in the effective magnetic strength of the coil core allows the spring to compress the carbon pile, with the result that more current flows through the shunt field of the generator and causes the generator voltage to increase. Conversely, when the current flows through the equalizer coils (F) in the opposite direction, its magnetic polarity is the same as that of the voltage coils (H); thus the magnetic strength of the core is increased. The added strength of the magnetic core decreases the spring pressure on the carbon pile and thereby decreases the field current and consequently the generator output voltage. Thus, we find that the direction of the current flow in the equalizer coil (F) determines whether the voltage of its generator will increase or decrease, and we should also understand that the amount of current flowing in the equalizer circuit governs the amount of change that occurs in the generator voltage output. Since the equal-

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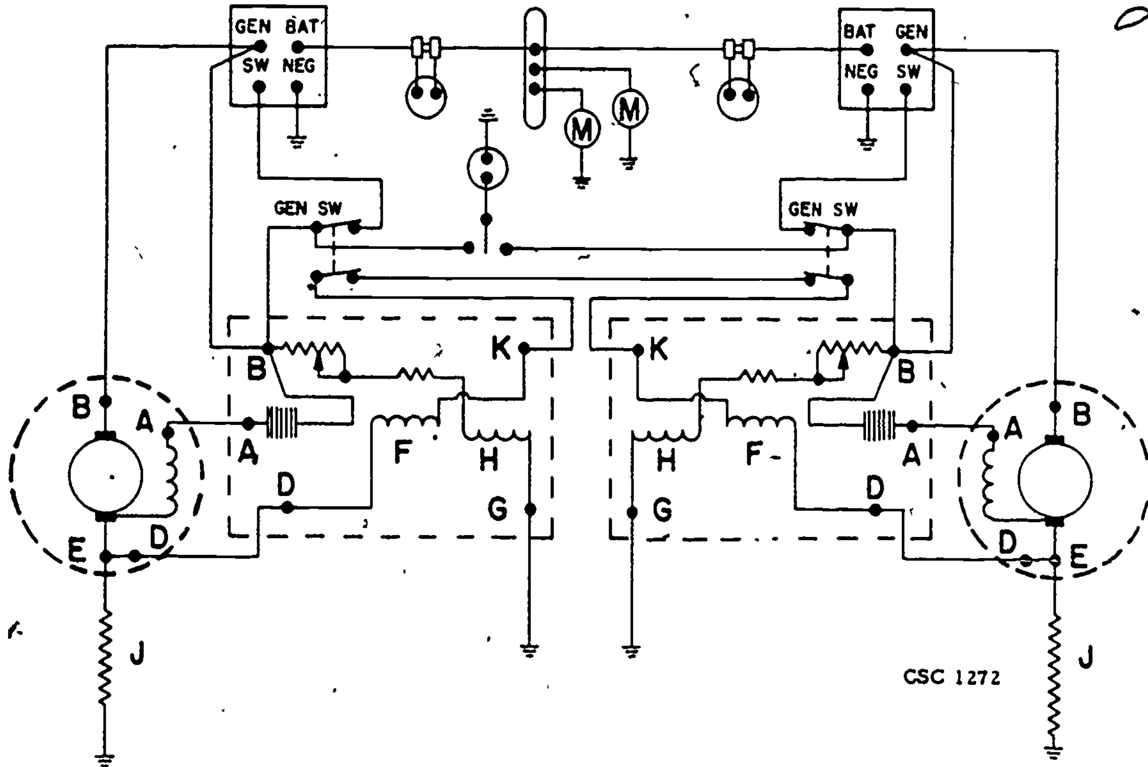

Figure 40. Multi-generator equalizer circuit.

izer normally can raise or lower the voltage of a generator only 0.3 volt, the voltage regulators first must be used to adjust the voltage outputs of their respective generators as closely as possible to enable the equalizer coils to maintain parallel operation.

13-18. If one generator of a paralleled system becomes inoperative, there is no current flow through its equalizing resistor (J), consequently, the voltage at the D terminal of that generator would be the same as if it were not sharing the load distribution. The current flow in the equalizer circuit would be such as to reduce the voltage of the operative generator by as much as 2 or 3 volts when large electrical loads are applied. To prevent this highly undesirable condition, the equalizer circuit of the faulty generator must be interrupted. This has been accomplished in some installations by physically removing the regulator of the inoperative generator system from its base. Some installations pass the "k" lead through one side of a double pole switch, as shown in fig. 40, the other side of which controls the operation of the corresponding reverse-current relay. Opening the generator switch then automatically opens the "k" lead and prevents the drop of bus voltage when the generator becomes inoperative. In systems that incorporate the field control relay, the equalizer circuit is completed through a set of normally closed contacts that open in the event of an overvoltage condition. If an overvoltage condition occurs in a system not having this protective equipment, a current would flow through the equalizer circuit in such a manner as to reduce the voltage of the high-current generator(s). If the field control relay is actuated by an overvoltage condition, the equalizer circuit for that generator is automatically opened, and so does not have any adverse effect on the operation of the remaining generators.

13-19. *Paralleling procedure.* After you have made the voltage regulator adjustments, increase the speed of all engines to their normal cruising range and close all generator switches. Next, apply an electrical load, such as lighting equipment, inverters, and radio equipment, equivalent to approximately the full-load rating of one generator. In some aircraft, the ratio of generator capacity to normal aircraft load is so great that it may be difficult to turn on enough equipment to obtain the above specified loads. In those instances, turn on as much equipment as possible. Next, observe ammeter readings. The difference between the highest and lowest generator currents should not exceed TO specifications. If the generators are not dividing the load properly,

first lower the voltage of the generator providing the greatest amount of current, and slightly raise the voltage of the lowest current-producing generator by adjusting the corresponding voltage regulators. Exercise care not to change the voltage to any great extent. After you have made all voltage adjustments, make a final check of the bus voltage by connecting the precision voltmeter from the positive bus to ground. The voltmeter should read 28 $\pm$ 0.25 volts. If the bus voltage is not within these limits, readjust all voltage regulators individually for 28 volts at no load, and then repeat the paralleling process.

13-20. In some aircraft installations, remote control of the voltage regulators is required. This means that the rheostat must be electrically separated from the voltage regulator. To keep all voltage regulators interchangeable, the voltage-adjusting rheostat is not physically removed or disconnected; instead, remote control is accomplished by turning the rheostat on the regulator assembly to its minimum resistance position and inserting another variable resistance in series with it. The remotely located rheostat may then be positioned in any convenient location. The primary purpose of this remote control arrangement is to provide a voltage adjustment near the ammeters to facilitate paralleling of the generators on aircraft using two or more generators. The rheostat on the voltage regulator assembly must not be used for making the voltage adjustments in installations with remote control rheostats.

13-21. *Generator control panel.* In the past few years, it has been the tendency to bring all of the individual circuit-controlling devices back into or onto one common unit. This unit is now called a generator control panel. The entire control panel is mounted so that it may be replaced very easily in the event of failure or malfunction of any one of its components. A generator control panel is a device associated with the newer generator installations. The purpose of the panel is to provide a compact installation that includes most of the various relays and voltage regulators. Obviously, such a compact arrangement should facilitate the testing, troubleshooting, servicing, removal, and installation of these components.

14. DC Generator System Troubleshooting

14-1. Aircraft must be kept at their highest efficiency at all times. Since most combat equipment is electrically operated, the power system must be kept in perfect operating condition. In addition to the combat equipment, the flight controls, radio, lights, guns, and many other devices are also dependent upon the electrical system. There are three sources of dc power for the electrical system: the battery, the ac generator through a T-R system and a dc generator. In this chapter our discussion will be limited to the dc generator system.

14-2. Troubles may develop at any time in a properly maintained generator system, but they are more likely to occur when operating the aircraft under the tremendous loads of combat conditions. In order to keep the system at its highest peak of efficiency, it is essential that the electrical repairman be able to recognize, diagnose, and eliminate troubles from the system at the earliest possible moment. In order to maintain and troubleshoot the generator system, you, the electrical mechanic, must intelligently apply your technical knowledge of each unit in the system.

14-3. **Generator Lead Identification.** To aid in troubleshooting and general work with generators, the aircraft electricians have developed a code of their own which is used to designate the various wires of the generator circuit. The capital letters "B" and "E" are assigned to the large-diameter wires which connect the B terminal of the generator to the GEN terminal of the reverse-current relay, and the E terminal of the generator to the ground, respectively. The lowercase "b" is used to designate the small-diameter wire which connects the GEN terminal of the reverse-current relay to the B terminal of the voltage regulator mounting base. The "a" lead is the small wire that connects the A terminal of the voltage regulator base to the A terminal of the generator. The "g" lead is the small lead that completes the circuit between the G terminal of the regulator base and the ground. Similarly, in multigenerator installations, the "d" and "k" leads are the small wires which connect the D terminal of the generator to the corresponding voltage regulator base, and the K terminal of one regulator base to the K terminals of the other regulator bases.

14-4. **Generator Trouble Indications.** Troubleshooting starts with the cockpit voltmeter and ammeter, because these instruments are wired into the circuit so that they give the pilot or engineer a continuous check on the output of each of the installed generators. A normal voltmeter reading is 28 volts and any deviation from this figure indicates that a fault exists somewhere in the system. A voltage indication that is only slightly higher or lower than the normal voltage could mean that the voltage regulator needs adjustment. Four types of voltage readings which indicate serious trouble are: (1) a reverse voltage reading, (2) a zero voltage reading, (3) a residual voltage reading, and (4) an excessive voltage reading.

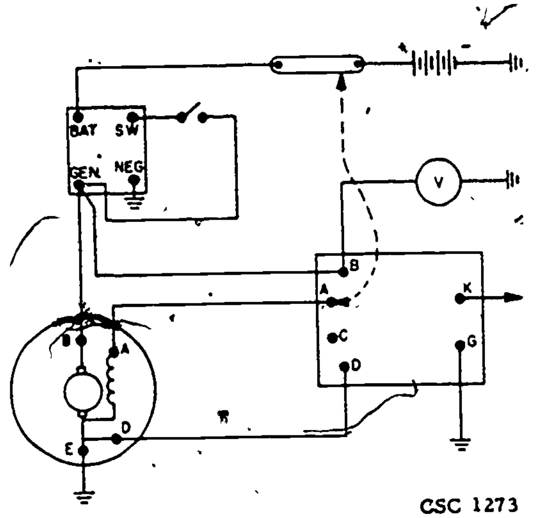

Figure 41. Voltmeter troubleshooting.

14-5. Before an intelligent diagnosis can be made, you must know what the desirable voltage output of the generator is under normal conditions, as well as the various causes of abnormal voltage readings. Since abnormal voltmeter readings tend to show the location of the troubles in particular parts of the circuit, you will find it helpful to learn the following generalized causes of certain abnormal voltages. If the cockpit voltmeter shows an abnormal voltage, the first thing to do is to connect a precision voltmeter into the circuit so that it is connected between B terminal of the voltage regulator base and ground. This insures that the cockpit voltmeter is giving a true indication of the operation of the system.

14-6. *Reverse voltage readings.* This type of voltmeter reading shows that the generator voltage output is reversed or that the voltmeter is connected incorrectly. A quick check with another voltmeter connected between B terminal of the voltage regulator base and ground will show whether the voltmeter or the generator is at fault. If the voltmeter has been replaced recently, there is a strong likelihood that the leads to the new instrument were placed on the wrong terminals. If the generator has just been replaced with a new unit, it is possible that the "B" and "E" leads at the generator have been reversed. If neither of the units has been replaced recently, the only possibility remaining is that the generator polarity has been reversed.

14-7. You can correct reversed generator polarity by flashing the field. You accomplish this by momentarily connecting a small-diameter wire between the A terminal of the voltage regulator base, with the regulator assembly removed, and a positive source of voltage (fig. 41) while the engine is running at an idling speed. This passes a current through the shunt field coils in such a direction as to restore the magnetism to its correct polarity. If the cockpit voltmeter is visible during this process, you should note a voltage reading during the field-flashing process because the armature rotates in the magnetic field produced by this current flow. The voltage reading should decrease to a residual value as the jumper wire is removed.

14-8. *Residual voltage readings.* When the generator is producing residual voltage, which ranges from 0.5 to 2 volts in value, the trouble must be in the field circuit. Since the voltage is no more than that which could be produced by the armature cutting the residual magnetism of the field pole pieces, it is only logical to assume that the trouble must be due to the lack of a current flow through the shunt field of the generator.

14-9. *Zero voltage readings.* With a cockpit voltmeter reading of zero volts, you should expect a trouble which would prevent the generator from producing any voltage, or which would cause the circuit to the cockpit voltmeter to be incomplete. A quick check with another voltmeter will show whether the voltmeter circuit is at fault, or whether the trouble lies elsewhere.

14-10. A zero generator voltage indication on the cockpit voltmeter can be caused by an open "B" lead, an open "b" lead, a short between "B" and "E," or faults within the generator, such as the loss of residual magnetism, poor commutation, or grounded positive brushes. All of these troubles will prevent the generator from developing a potential, or the voltmeter from indicating a potential.

14-11. *Excessive voltage readings.* Excessive voltage conditions are caused by a complete lack of regulation of the current flowing through the shunt fields. A short circuit between the B and A terminals at either the generator or regulator terminals or between the "B" or "b" lead and the "a" lead, would provide a low-resistance path for current to flow in parallel with the carbon stack. It would allow full generator voltage to be applied to the shunt field, resulting in an excessive voltage condition. Other reasons for excessive voltage include an open in the voltage coil circuit of the voltage regulator or an open "g" lead which connects the G terminal of the voltage regulator mounting base to the ground.

14-12. Removal of the voltage regulator assembly from its mounting base while the trouble exists is one quick way of determining approximately where the trouble lies. When the voltage regulator is removed, the shunt field current should be interrupted and the voltage should normally decrease to a residual voltage value.

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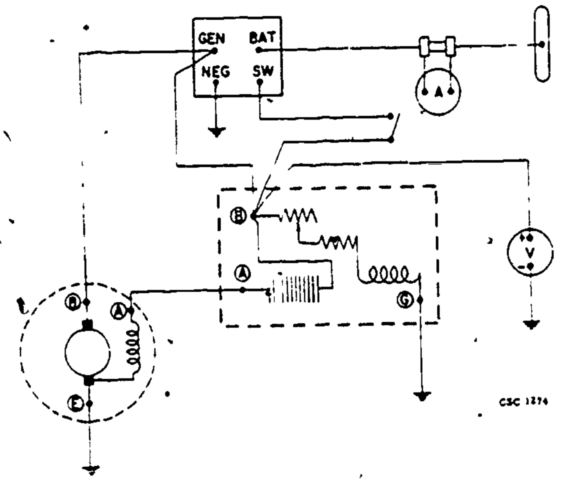

Figure 42. Single-engine generator installation.

If the trouble lies in the voltage regulator or the "g" lead, when the voltage regulator is removed, the system voltage will drop to its residual value. If the trouble is a short circuit in parallel with the regulating resistance, the trouble will persist when the regulator assembly is removed and the voltage will continue to be excessive. If you know the general nature of the trouble, your next step is to locate and eliminate it from the system.

14-13. **Troubleshooting by Use of a Voltmeter.** The process of locating troubles in the generator system is made easier not only by taking voltmeter readings between some of the terminals and the ground, but also by taking voltmeter readings between specific terminals. Figure 42 shows a typical single-engine generator system which we will use as a basis for explaining the voltage readings obtained at and between the various terminals, as shown in table 3.

14-14. To obtain the readings shown in the table 3, a particular generator was driven at the same rpm with each trouble in the circuit. A no-load condition also existed as would be the case in the event of a trouble in the circuit. The voltage readings for other types and models of generators vary from the values shown, but these suffice to demonstrate the method for systematically locating the trouble. All voltage readings were taken with the generator running and the voltage regulator assembly mounted on its base.

14-15. At this point, let us again remind you that the voltmeter measures the difference in potential between the two points to which it is connected. If the potential at both terminals of the voltmeter is exactly the same with respect to some other point, the meter registers zero volts; but if there is a difference in voltage, the meter indicates the difference in emf and not the voltage present at either of the terminals.

14-16. One more word of explanation may be helpful at this point. In table 3 the first two check-points mentioned is assumed to be the positive terminal. The voltmeter positive lead should be connected to it and the voltmeter negative lead connected to the second-mentioned terminal or other reference point.

14-17. *Case Nr. 1.* The voltage readings recorded for this case were taken from a normally operating generator installation for reference purposes. The cockpit voltmeter registers 28 volts, indicating that the regulating equipment is performing normally.

14-18. At the voltage regulator the voltage is always checked between the B terminal and the ground (structure), and then between B and G terminals of the mounting base. If no trouble exists in the circuit, the same voltage should be noted in these checks as has been shown on the cockpit voltmeter. The second part of the check (between B and G terminals) is for the purpose of checking the "g" lead. If the wire is intact, there is the same difference in potential between B and G terminals as there is between the B terminal and the ground. Should the "g" wire be broken, terminals B and G would be at the

TABLE 3

TROUBLESHOOTING VOLTMETER READINGS VOLTAGE READINGS

Case			At Voltage Regulator Base						At Relay	At Generator			At Voltmeter		
Nr.	Trouble	Cockpit Voltmeter	B to G'nd	B to G	A to G'nd	A to G	B to A	G to G'nd	Gen to G'nd	B to E	A to E	B to A	+ to G'nd	− to G'nd	+ to −
1.	None	28	28	28	7	7	21	0	28	28	7	21	28	0	28
2.		0	28	28	7	7	21	0	28	28	7	21	0	0	0
3.		0	28	28	7	7	21	0	28	28	7	21	28	0	28
4.		0	0	0	0	0	0	0	1.5	1.5	0	1.5	0	0	
5.		30+	30+	30+	30+	30+	0	0	30+	30+	30+	1.5	30+	0	30+

same potential, and the voltmeter connected between them would indicate zero volts. The next check is from A terminal to ground and then between A and G terminals. With this check you can be certain that the carbon pile is offering some resistance to the flow of current, because the voltage at A terminal should be somewhat less than that available at B terminal.

14-19. By connecting the positive terminal of the voltmeter to the B terminal and the negative terminal to the A terminal, we should be able to measure the voltage that is being expended to push the current through the field resistance of the regulating unit.

14-20. The next check in the sequence is to connect the voltmeter between the G terminal of the voltage regulator base and the ground (structure of the aircraft). Normally these two points are connected by an electrical conductor (the "g" lead) and are therefore at the same potential, so the voltmeter should register zero volts.

14-21. The next check is made by connecting the troubleshooting voltmeter between the GEN terminal of the reverse-current relay and the ground. With everything operating normally, there should be the same, or a slightly higher voltage indicated here than was registered on the voltmeter when it was connected between the B terminal and the ground at the voltage regulator base.

14-22. From this point, proceed directly to the generator to finish the checks. The first check is between B and E terminals, where you should note a voltage that is equivalent to that previously measured between B and the ground at the voltage regulator. However, the voltage at B and E may be slightly higher to compensate for the emf loss due to the resistance of the power distribution circuit. The second check is between A and E terminals. This voltage should be approximately the same as that previously measured between A terminal and ground at the voltage regulator base. The third check is between B and A terminals of the generator. Again, the voltage at these terminals is found to be the same as that between terminals B and A at the voltage regulator mounting base.

14-23. The last three columns of table 3 are troubleshooting voltmeter readings taken at and between the terminals of the cockpit voltmeter. Such readings are useful in those cases where the installed meter indicates some voltage other than that which is present in the system. As shown, the voltage is checked between the positive terminal and the ground and between the positive and the negative terminals. The troubleshooting meter should register the system voltage in the first check, zero volts in the second location, and, finally, system voltage again in the third check if all circuit components are complete. If all readings are normal and the installed meter still fails to register, any trouble must be within the meter.

14-24. *Case Nr. 2.* In this case the first trouble indication is a zero reading on the cockpit voltmeter. A quick check with the troubleshooting meter shows that the voltages throughout the system are normal until the installed meter is reached. When making the check between the positive terminal and ground at the meter, the reading is zero volts. Identical readings are obtained between the negative terminal and the ground, and between the positive and negative terminals. A quick look back at figure 42, which you should be thoroughly familiar with, shows that a wire connects the positive terminal of the voltmeter to B terminal of the voltage regulator base at which 28 volts had previously been noted. If this connecting wire were complete, the same voltage should be present at the positive terminal of the voltmeter. The zero reading at the positive terminal of the voltmeter indicates that the voltmeter positive lead is open.

14-25. *Case Nr. 3.* Once again a discrepancy exists between the reading of the installed voltmeter and the readings noted during the systematic check with the troubleshooting voltmeter. Although the reading on the installed meter is zero, the test meter shows that the voltages throughout the system are normal up to the terminals of the installed meter. There is 28 volts at the positive terminal, zero volts between the negative terminal and the ground, and 28 volts again when the test meter is connected between the positive and negative terminals of the questionable meter. In other words, there is voltage to the meter. The negative wire is complete; otherwise no reading would have been evident in the last check. Thus the only place where trouble can exist is within the installed meter. Removal and replacement of the meter will correct this discrepancy.

14-26. *Case Nr. 4.* For this condition the zero reading on the cockpit voltmeter was substantiated by similar readings on the test meter when it was connected to and between the terminals of the voltage regulator mounting base. Further checks between the GEN terminal of the reverse-current relay and the ground indicate a small voltage which is easily identified as residual voltage. The fact that there is a voltage here indicates that the generator is capable of producing a voltage if properly excited. It also indicates that the "B" and "E" leads of the generator form complete circuits; otherwise it would not have been possible to complete the circuit for the test voltmeter. Although the cockpit voltmeter reads

zero volts, the troubleshooting procedure revealed no voltage at the voltage regulator base. Thinking again about the circuit, you can reason that the only difficulty which could cause this set of circumstances is an open "b" lead.

14-27. *Case Nr. 5.* In this case the excessive voltage indicated on the cockpit voltmeter shows that there is a definite lack in control over the current flowing through the shunt field circuit. The voltmeter checks from terminal B to ground and then from terminals B to G show 30± volts indications, so the possibility of the previous trouble has been eliminated. The first clue as to the exact nature of the trouble comes to light when the troubleshooting meter is connected between terminals B and A. You know that there is current flowing in the "a" lead; otherwise there would be no excessive voltage indicated on the cockpit voltmeter. You also know that the carbon pile is a resistance. If a current flows through a resistance, there must be a difference in potential between the two ends of the resistance. When the troubleshooting voltmeter is connected across the resistance, between terminals B and A of the regulator, there is no voltage indicated, so the two points must be at the same potential with respect to the ground. You may wonder how this can be. The explanation is simple. According to the observed voltmeter reading, there is no resistance between terminals B and A; therefore, a short circuit must exist somewhere in the circuit between B and A. This condition would place both points at the same potential and provide a path for the field current to flow around the regulating resistance rather than through it. Obviously the voltage regulator would have no control over the field current or the voltage output of the generator.

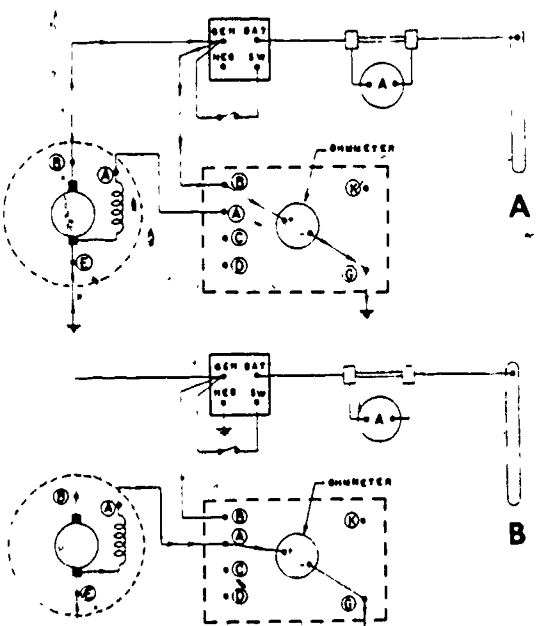

Figure 43. Ohmeter troubleshooting.

14-28. **Troubleshooting by Use of an Ohmmeter.** When trouble developes in an aircraft electrical circuit where power is furnished only by the aircraft generator, the ohmmeter is the most practical instrument to use for locating the trouble. CAUTION: When you check any circuit with an ohmmeter, be sure that the battery switch is in the OFF position and that the generator is not running. The circuit being checked by the ohmmeter must have no source of electrical power other than that contained in the ohmmeter itself. You will find it most convenient to check the generator circuit at the voltage regulator base while the voltage regulator is removed.

14-29. *Check Nr. 1.* The first check you make is to connect the ohmmeter to terminals B and G of the voltage regulator base. In this way you are checking the continuity and measuring the resistance from B on the regulator to the GEN terminal of the RCR; through the generator (B-E) to ground and from ground to E on the regulator base, as shown in part A of figure 43. The resistance of the circuit as indicated on the ohmmeter is approximately one-half of an ohm. No definite value can be cited because the resistance of the circuit is dependent upon the make and model of the generator and the length of the various leads. If the ohmmeter indicates an extremely high resistance for the circuit, the trouble will be an open circuit in one of the circuit components being checked. Conversely, if the ohmmeter reading is indicating zero ohms resistance, the trouble will be a ground somewhere between B on the generator and B on the regulator base that is permitting a circuit to be completed around the principal resistance in the circuit (the armature).

14-30. *Check Nr. 2.* The second check is performed by checking the circuit from the A terminal on the regulator base to the G terminal, as shown in part B of figure 43. When per-

forming this check, you will be checking the continuity, the generator shunt field, the "E" lead on the generator, and the "G" lead at the voltage regulator base. At the same time, the resistance value indicated on the ohmmeter will afford a means of locating troubles. In this case, as in so many other cases, no single exact resistance value can be cited that would be standard for all generator installations. The resistance of the shunt field varies from 2 to 3 ohms and may range as high as 13 or 14 ohms on some older models of generators. You may assume that a reading of 3 ohms is a normal one for the check from terminal A to terminal G. An ohmmeter reading that is much higher than normal indicates that there is an open circuit, while a reading that is only slightly higher than normal may indicate loose or dirty connections somewhere in the circuit. A lower than normal resistance in this circuit indicates a partially shorted field winding, whereas a zero resistance indicates that the field winding is completely short circuited, or that the lead between A of the voltage regulator and A on the generator is grounded.

14-31. *Check Nr. 3.* Finally, as shown in part C of figure 43, connect the ohmmeter to terminals B and A on the regulator base. This connection should cause the ohmmeter to read the combined resistance of the field and armature, since they are in series with each other in this case. This should amount to approximately 3½ ohms. This operation not only checks the continuity of the lead between A on the regulator and A on the generator, the armature, the "B" lead, (between B on the generator to B on the regulator) but it also indicates the general condition of these system elements.

14-32. By comparing the ohmmeter readings thus obtained with normal readings and analyzing the circuit check for each step, you can systematically eliminate certain components as sources of trouble and eventually arrive at a sound determination.

14-33. **Schematics and Wiring Diagrams.** So far in this chapter only those troubles located between the generator and the voltage regulator have been discussed. What about malfunctions in the rest of the generator system? It is certain that eventually you will have to troubleshoot the entire generator system to detect the cause of a trouble. The remainder of this discussion, therefore, is devoted to those technical references you must be familiar with in order to diagnose and repair troubles quickly in any electrical system. Since you are familiar with dc generator systems by now, let's continue by using these systems as references.

14-34. In addition to the test equipment you need to help you troubleshoot, you also have to be completely familiar with the use of schematics and wiring diagrams. These are found in the –2 maintenance handbooks for the aircraft on which you are working.

14-35. *Schematics.* A typical schematic of a dc generator system is shown in figure 44. This schematic was taken from an aircraft TO—2–6, Organizational Maintenance, Electrical Systems. This schematic has been selected as one typical of the type you may use in your day to day work. Now, let us examine the figure to see how it can help you in your work. For one thing, schematics always show the internal wiring of the components in the system, such as the voltage regulator and the RCR. Note also that pin letters of CANNON plugs are given, such as shown in the dimming relay and the generator field control relay. Many schematics also show the location of the units in the aircraft. For example, the voltage regulator shown is located in the LH POWER BAY as noted directly beneath the voltage regulator in the schematic.

14-36. A schematic is also useful in pointing out differences in wiring that might exist between different versions of the same model aircraft. For example, note in the illustration that there are two wires connected to E of the generator. One wire is marked by a 2 within a small square; the other wire by a 3. If you look at the legend directly beneath the schematic, you see that aircraft numbered –1 through –65 are wired so that the wire from E of the generator is connected to the loadmeter shunt, while aircraft –70 and later are wired so that E of the generator is connected to the ground. These latter aircraft have the loadmeter wired in the circuit as shown in the upper left hand corner.

14-37. You can see then, that schematics are very useful in determining how a system should operate and approximately where parts are located. For actual troubleshooting, however, it is best to use the wiring diagram, which, if used in conjunction with the schematic, helps you to quickly locate and diagnose electrical malfunctions.

14-38. *Wiring diagrams.* The wiring diagram for the generator system previously shown schematically in figure 44 is Part I in foldout 1, at the back of this volume. You can see that there is quite a bit of difference. Whereas the schematic showed only one wire connected between B of the generator and the GEN terminal of the RCR, the wiring diagram shows that in reality there are three wires from B of the generator to the disconnect; and from the disconnect to the

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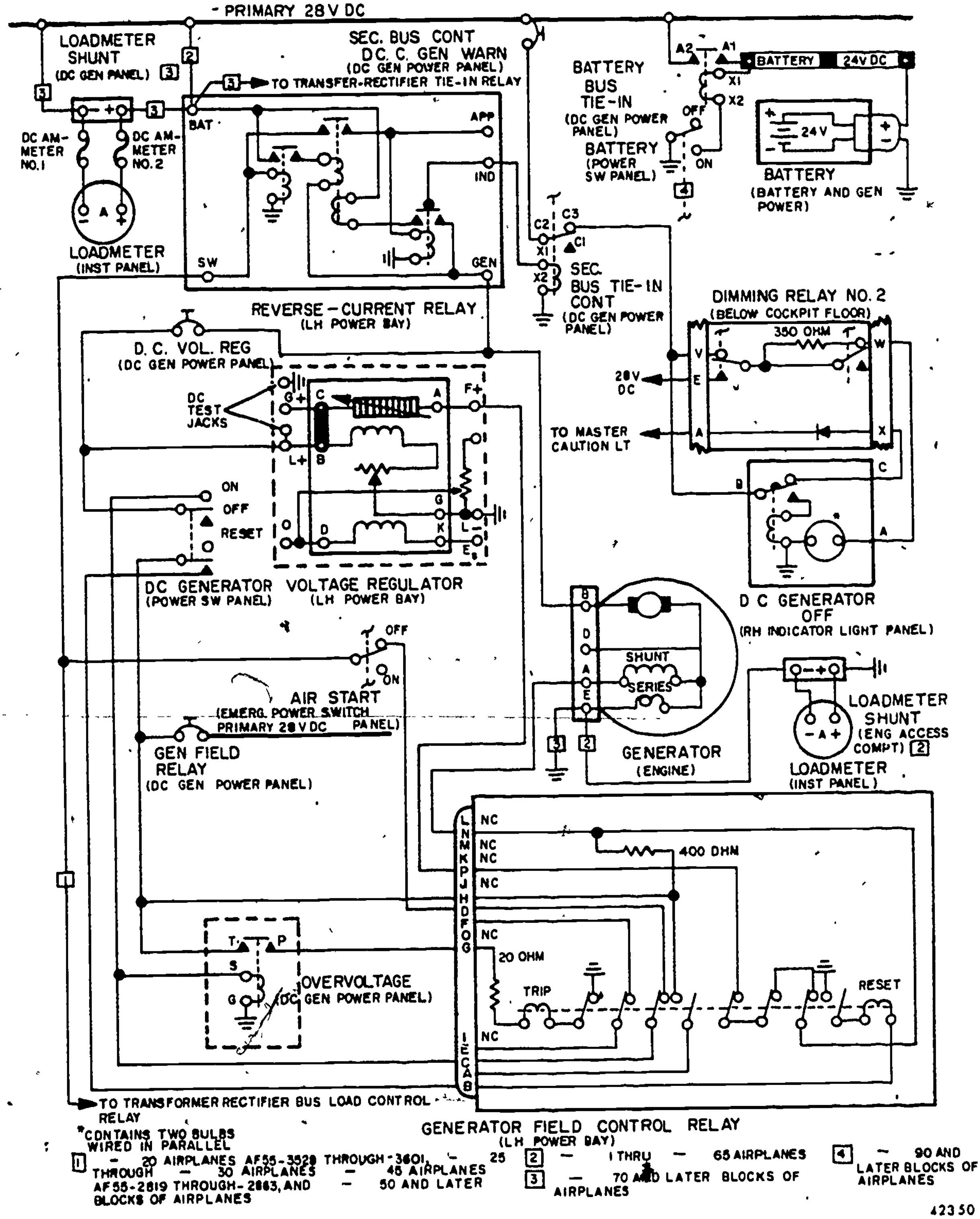

Figure 44. Generator system schematic.

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GEN terminal of the RCR there are six wires. You can see also that each wire is identified with a letter-number code. To refresh your memory let's review briefly what each part of the wire number means, using one of the wires connected to B of the generator as an example. We'll use wire number 1P1A6. The Nr. 1 means that there is more than one wire used in this particular circuit. The letter P represents dc power. All wiring diagram handbooks have a circuit identification code that tells you what these letters stand for. (For example, X is ac, L is lighting, etc.) The next part of the wire number is the Nr. 1, which is the wire number itself. The letter A identifies the wire segment. The wire segment letter changes at each break in the circuit. For example, the next segment letter would be B, then C, and so on. The last number in the wire number indicates the wire size, in this case, Nr. 6. Note that after the wires from B of the generator pass through the generator disconnect, it is now a six-wire system. The wire segments are marked B, and the size has decreased to Nr. 10.

14-39. Although wiring diagrams do not show the internal circuitry of components, they do provide certain essential information regarding those components. For example, beneath the RCR, note the legend "K503 Reverse-Current Relay." If you refer to the reference item list shown in Part II, foldout 1, you can find the nomenclature of the item, the part number, and the station number where the item is located in the aircraft. In this example, K503 is listed as a Relay, Reverse Current, part number AN3025-1, and it is located at station 222.5 LH. The reference item list is part of the wiring diagram shown in foldout 1. You can also determine AN connector numbers and pin numbers, the location, and often the part numbers for these items from the wiring diagram.

14-40. This is all that is going to be said about schematics and wiring diagrams. Familiarity with them comes about as you use them. Although these drawings may vary slightly among different aircraft, they are all basically the same. One word of caution might be added at this point. You should always check the -2 handbook to make sure you know what each electrical symbol stands for. Although aircraft electrical symbols have been fairly well standardized, there is enough variation among manufacturers to warrant your making sure of what each symbol represents.

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CHAPTER 4

Transformer-Rectifier Power Systems

THE CONTINUING trend toward the use of alternating current as the primary source of electrical power on many aircraft has necessitated the use of transformer-rectifier (T-R) units as the primary source of direct-current power. This means that you, the aircraft electrician, must know the principles of operation of the various types of T-R units, including the special-purpose types used in aircraft battery charging systems. You must be completely familiar with the effects that a varying load has on each type of T-R unit so that you can successfully troubleshoot malfunctions and maintain T-R systems.

15. Transformer-Rectifiers

15-1. A transformer-rectifier is a device that changes alternating current into direct current. All T-R units consist of a transformer section that reduces the input ac voltage, and some means of changing ac into dc. You may consider that there are three types of T-R units: the dry-disc rectifier type, the static type, and the special purpose type. Since the rectifier type is probably the most widely used, we will discuss it first.

15-2. **Rectifier Type T-R Unit.** The rectifier type T-R unit consists of a transformer, a bank of dry-disc rectifiers, and a cooling fan. A schematic of this unit is shown in figure 45.

15-3. The transformer consists of a wye-wound primary winding and two secondary windings (a wye winding and a delta winding). The three-phase ac input is applied through terminals A, B, and C where it is stepped down. The output across the wye-delta secondary is applied to the bank of dry-disc rectifiers and the dc output is furnished to the distribution system from the terminals marked + and −. The T-R unit shown in figure 45 operates from a 200-volt, three-phase, 400-Hz ac system, and the output is rated at 24 volts and 100 amperes. Some aircraft dc power systems require T-R units with only a 50-ampere output. A 50-ampere T-R unit is almost the same as the 100-ampere unit, except that a delta connected secondary is used with the 50-ampere unit and a wye-delta connected secondary is used with the 100-ampere unit.

15-4. The cooling fan also receives its input ac from the main power source. The purpose of the fan is to draw air across the bank of rectifiers. Proper operation of the fan motor is very critical on dry-disc T-R's. If the fan motor should fail while the T-R was operating under a load, the unit would tend to overheat and fail within a short period of time; and the load on the distribution system at that time would have to be divided among any remaining T-R units in the system.

15-5. Figure 46 shows a typical T-R unit installation. Note that each T-R unit is labelled with an arrow that indicates the proper direction of airflow through the unit. Air is always exhausted at the terminal end. In installations such as shown in figure 46, it is important that all the T-R units exhaust in the same direction; if one should be exhausting in an opposite direction, the other T-R's would tend to draw in hot exhaust air which would raise their operating temperatures. On many aircraft, proper operation of the cooling fans is an item of inspection by the aircrew during their preflight inspection.

15-6. **Static Type T-R Unit.** The static type T-R unit can be found on many later model aircraft, and it serves the same purpose as the more conventional T-R unit, we discussed previously. It delivers 24 volts dc at either 100 amperes or, in some cases, 200 amperes. It operates on a different principle, however, as you can see by examining the schematic diagram shown in figure 47.

15-7. The transformer section consists of two separate transformers; one transformer has a wye-connected primary and a 3-wye secondary, and the other transformer has a delta-connected primary and a 3-wye secondary. Both the primaries are connected in parallel to the 200-volt, three-phase, 400-Hz ac input. The turns-ratio of the two secondaries are so adjusted that the output

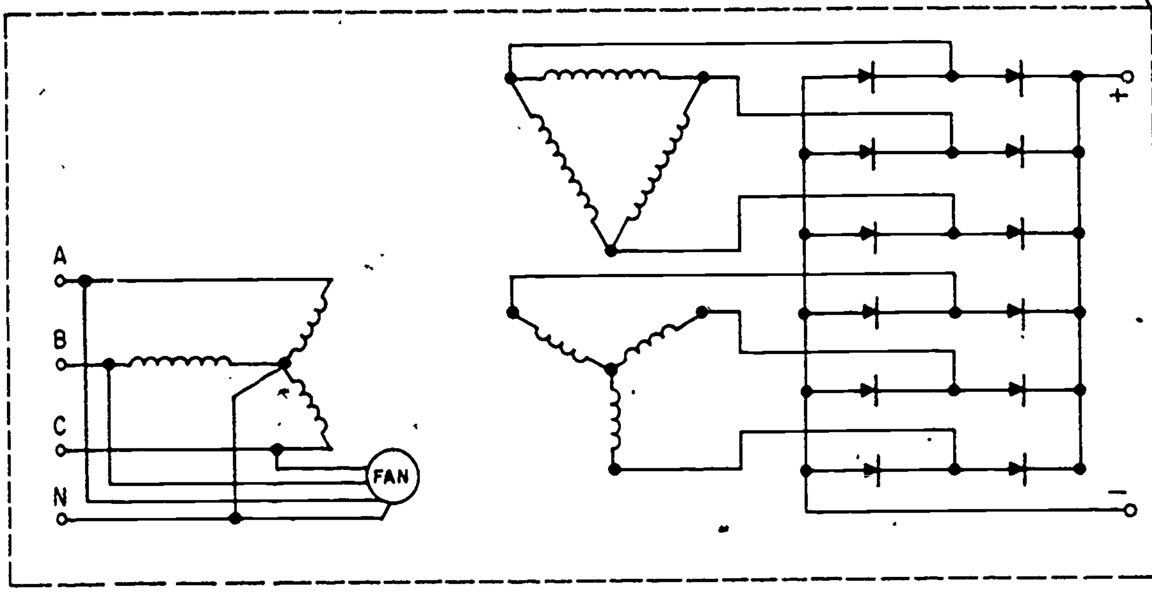

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Figure 45. Rectifier type T-R unit.

voltages are the same and can be paralleled together. The common connection of the ac portion of each secondary winding is interconnected through an interphase transformer that suppresses drift current between the secondaries, bleeding them off through the coils center-tapped to the negative terminal. The low-loss silicon diodes provide the necessary rectification. Due to the use of the silicon diodes, these T-R units need no cooling other than that furnished by convection. The dc output is furnished through the terminals marked + and −.

15-8. **Special-Purpose T-R Unit.** To maintain the state of charge of a nickel-cadmium battery, it is necessary to provide a more closely controlled source of battery charging power than that provided by a conventional battery charging rectifier. For this reason, many aircraft in which nickel-cadmium batteries are installed use a special type of T-R unit known as a battery charge T-R unit. A schematic diagram of a typical battery charge T-R unit is shown in figure 48. It is rated at 28.5 volts dc at 25 amperes.

15-9. The three-phase ac input from the primary ac power source is applied through a three-phase stepdown transformer, and the output is applied to six silicon-power rectifiers in a six-phase half-wave arrangement. This arrangement is more efficient than a full-wave connection, since the load current does not have to flow through two rectifiers in series. By this method of heating and the need for voltage regulation are reduced because there is less voltage drop across the rectifiers. Although the voltage regulating requirements are somewhat reduced, some regulation is required so that the output voltage of the T-R unit rises as the load current is increased. To obtain this characteristic, a self-saturating, variable reset component (MA1) is placed in series with the center tap of each transformer winding, and functions to regulate the output of two rectifiers. With this arrangement only three regulating cores are required for the six rectifiers, and the control circuitry is reduced to a minimum, as shown in figure 48.

15-10. The required voltage regulation is provided by a special voltage-sensing network, which includes load current compensation and a silicon voltage reference diode. The sensing network consists of resistor R4, reference voltage diode CR7, and the parallel combination of R6 and RT1. The output of this sensing circuit is applied to CW2 on the regulating core (MA1). A load reference signal is provided by CW1 which is in series with the load. The function of CW1 is to minimize circulating currents in the control circuit caused by voltage induced in the winding (CW2) when the reactors are absorbing a voltage integral.

15-11. The rectified current pulse flowing through the main winding of the reactor cores produces saturation. The reactor cores are made of a material which has a square top hysteresis loop, which means that the cores are left in a saturated condition at the end of each current pulse. If there were no current flowing in the control windings, the cores would remain saturated and the output voltage would be maximum.

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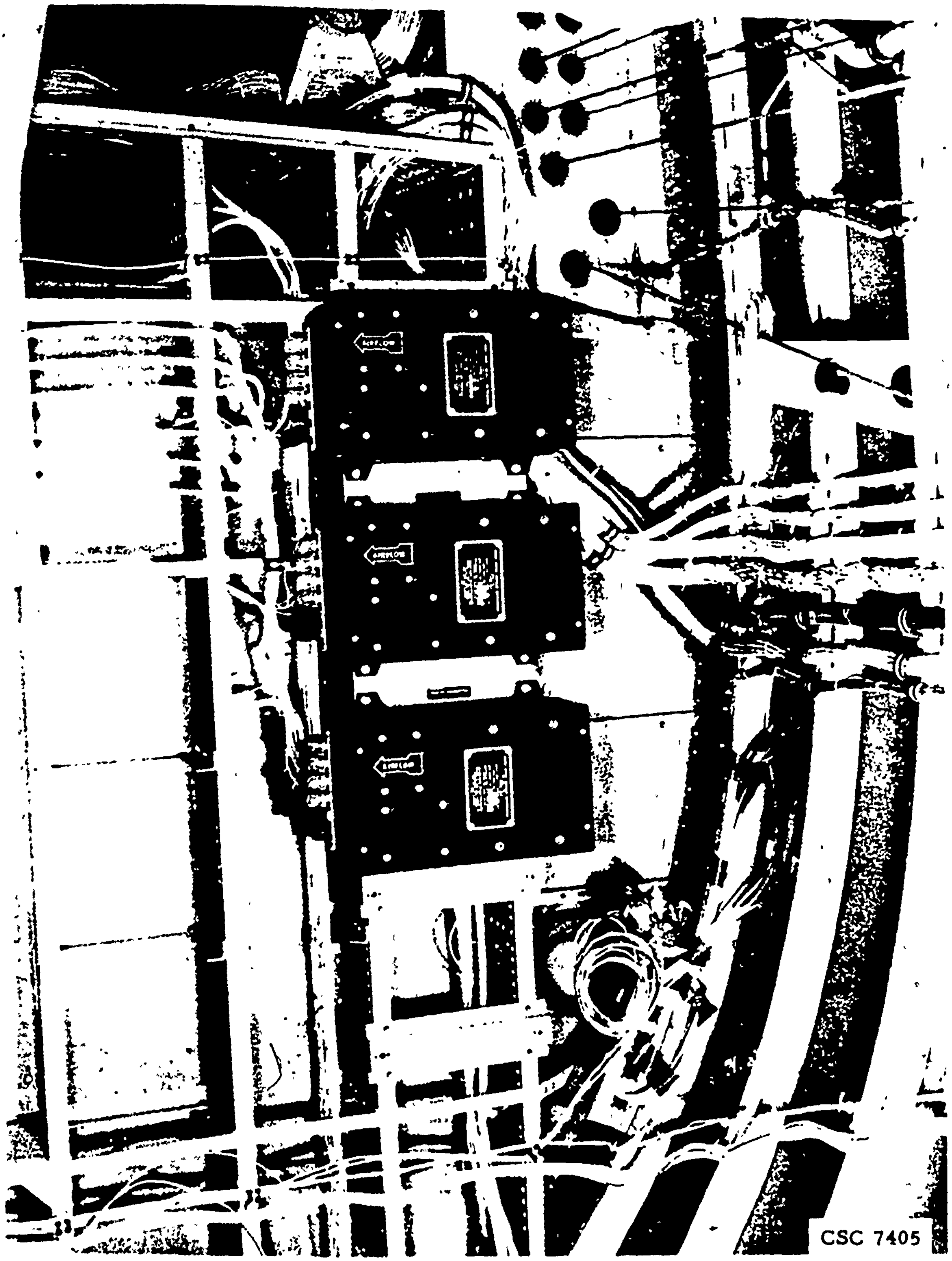

Figure 46. T-R unit installation.

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Since the regulating elements of this circuit function as static switches which are either full on or full off, it can be said that when the cores are saturated the switches are full on.

15-12. It is the function of the control circuit current to reset (bias) the cores after each current pulse so that the cores will absorb a voltage integral from the next current pulse during the time the flux in the core is driven from the reset (biased) value to saturation. In other words, during a current pulse the control circuit must determine the magnitude of the pulse and pulse duration or how long the switch will be turned on.

15-13. When the battery is low, the control circuit will cause the switch to be closed for a longer period of time and the magnitude of the pulse will be greater than that for a battery that is at or near a full charge.

15-14. The thermistor circuit consisting of RT1 and R6 is incorporated into the circuit to compensate for temperature changes due to load that would affect the operating characteristics of the unit. RT1 has a negative temperature coefficient and R6 has a positive temperature coefficient. Any changes in temperature that would affect the resistance of the output circuit are thus canceled out.

16. Transformer-Rectifier Testing

16-1. You can test a T-R unit by applying various loads to the unit to determine that the output voltage remains within the allowable limits. The specifications outlined in this section apply only to the typical units that we have discussed. You should always refer to the appropriate technical directive before testing any T-R unit.

16-2. **Rectifier Type.** One of the tests you may give to this T-R unit is the voltage regulation test. The test consists of applying 400-Hz ac at 195 volts to the input measuring the dc input when a 100-ampere load is connected. The output voltage must not be lower than 24 volts nor higher than 31 volts.

16-3. You should also test this unit for insulation breakdown. You perform this test by first shorting the four input terminals together, and the two output terminals together, then ap-

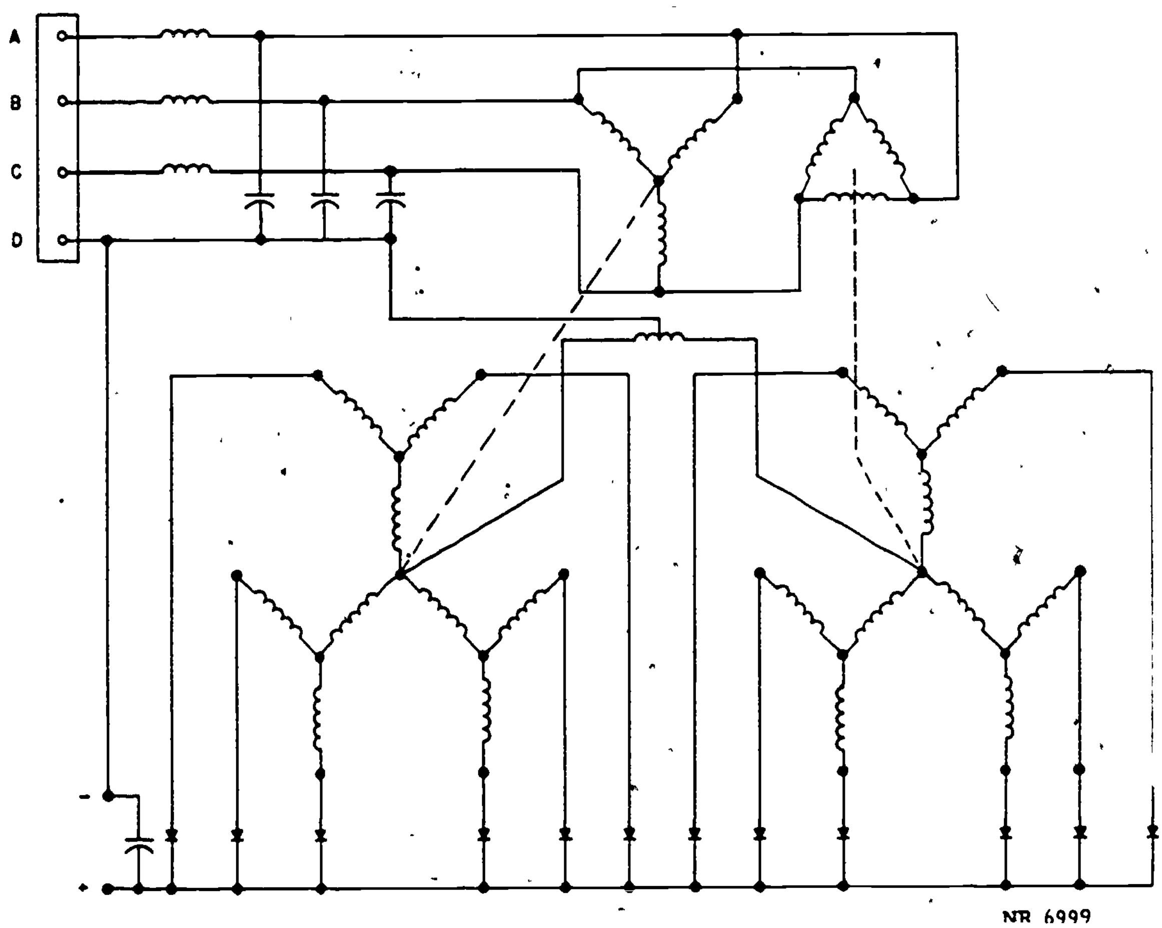

Figure 47. Static type T-R unit.

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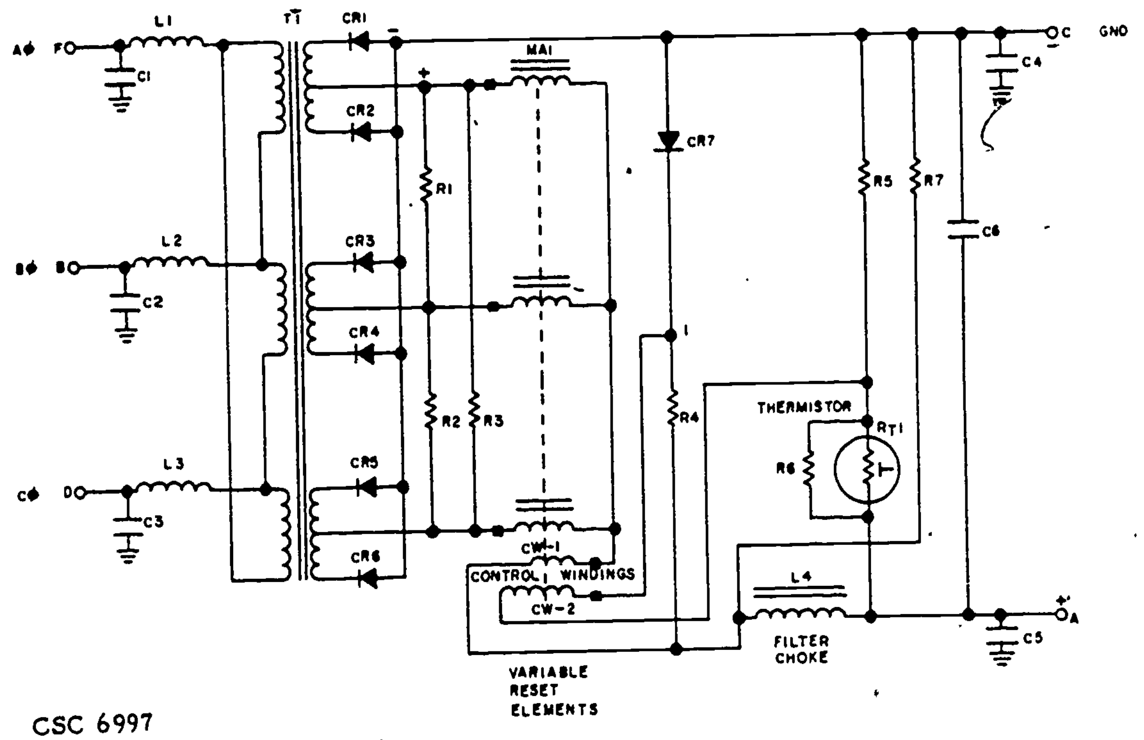

Figure 48. Battery charging T-R unit.

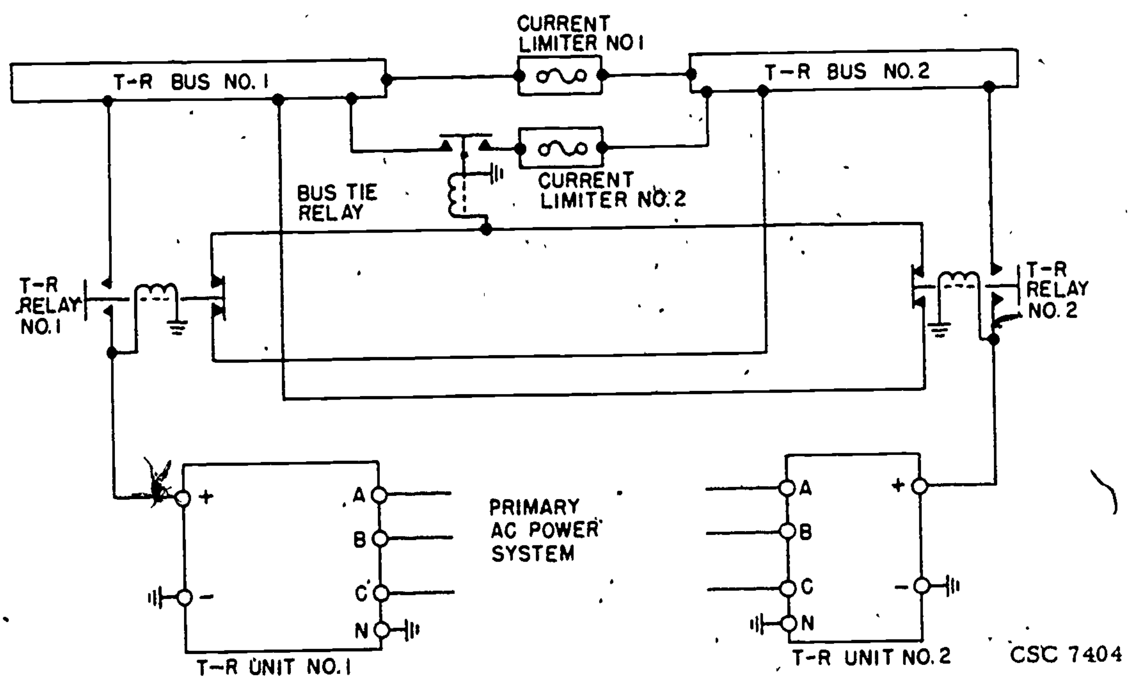

Figure 49. T-R unit distribution system.

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TABLE 4
BATTERY CHARGER T-R TEST VOLTAGES

Load (Amperes)	Output Voltage (D-C)
0	27.8 to 28.8
4	28.9 to 29.7
10	28.2 to 30.9
25	26.5 to 29.8

plying 60-Hz ac at 500 volts between the two sets of terminals for 1 minute. You accomplish the second part of the insulation breakdown test by shorting all the terminals together and applying 60-Hz ac at 500 volts between the shorted terminals and the case of the unit.

16-4. Another part of the test procedure for rectifier type T-R units is to check the operation of the cooling fan motor. Air is always drawn across the bank of rectifiers and exhausted at the terminal ends.

16-5. **Static Type.** The tests you will be giving to static T-R's are basically similar to tests for those types we have already discussed. The insulation breakdown test is performed under approximately the same conditions. The voltage regulation test, however, has significant differences. Before testing the static T-R, you should operate the unit for 30 minutes with 400 Hz ac at 200 volts, with a 100-ampere load. After the unit has reached normal operating temperature, the output voltage must be between 26.5 volts and 26.9 volts. Next, decrease the load to 10 amperes; the output voltage must now be between 28.375 volts and 29.125 volts. In the next part of the test, you increase the load to 100 amperes and decrease the input ac to 196 volts. In this case, the output voltage should not be less than 26 volts nor higher than 31 volts. In the last part of the voltages regulation test, you increase the input ac to 210 volts and decrease the load to 1 ampere. Again, the output voltage must not be less than 26 volts nor higher than 31 volts.

16-6. **Battery-Charging Type.** The only test you usually give to a battery-charging T-R is the voltage regulation test. You should apply an input voltage of 200 volts ac at a frequency of 400-Hz to the unit for at least 60 minutes to allow it to reach its normal operating range. No load should be applied during the warmup period. After the warmup period, apply the loads listed in table 4 for 2 minutes each, and check to see that each load results in the proper voltage output as shown in the table.

17. T-R Power System and Maintenance

17-1. Now that you are familiar with the principles of operation of various types of T-R units, let's turn our attention to T-R power distribution systems. In your work as an aircraft electrical repairman, you will encounter a wide variety of T-R power distribution systems. The systems vary both in the type of unit or units used and in the output ratings; for example, you have already seen that the rating of T-R units varies from 25 to 100 amperes. Some of the newest aircraft use T-R units having a 200-ampere capacity. Nevertheless, the operating principles remain the same as for those units we have already discussed. Now, let's begin our discussion with the description and operating characteristics of a typical T-R power system.

17-2. **T-R Power System.** Figure 49 is a schematic of a typical two T-R unit distribution system. Both T-R units receive their input power from the primary ac power source; and as soon as the primary source is energized, the T-R units automatically begin producing dc. The output of each T-R unit is connected to a T-R relay which has two sets of contacts. One set is used to connect the output of the T-R unit to the T-R bus. The other set of contacts is used when a T-R unit fails during operation or fails to start when the primary ac source is energized. This will be discussed later.

17-3. Note that the T-R buses are interconnected by current limiter Nr. 1. The buses can also be connected through current limiter Nr. 2 when the bus tie relay is energized. At first glance, current limiter Nr. 2 may seem superfluous to you, but this is not the case. To understand the function of the current limiters, let's assume that T-R Nr. 1 develops an internal short during operation and puts a higher than normal load on the distribution system. T-R relay Nr. 1 cannot become deenergized because it receives power from T-R bus Nr. 2 through current limiter Nr. 1. If the load on the T-R buses becomes excessive due to the faulty T-R unit, current limiter Nr. 1 will blow and open the circuit between the buses. Now, T-R relay Nr. 1 can deenergize. When it opens, its other set of contacts closes and completes a circuit between T-R bus Nr. 2 and the bus tie relay. When the bus tie relay is energized, the T-R buses are interconnected by current limiter Nr. 2. You can see, then, that the current limiters, in conjunction with the bus tie relay, serve these two purposes. they insure that both the T-R buses receive power in the event that a T-R unit fails during operation, and they prevent a faulty T-R unit from causing an excessive load on the distribution system.

17-4. If either T-R unit should fail to start when the primary ac source is energized, the corresponding T-R relay will fail to become en-

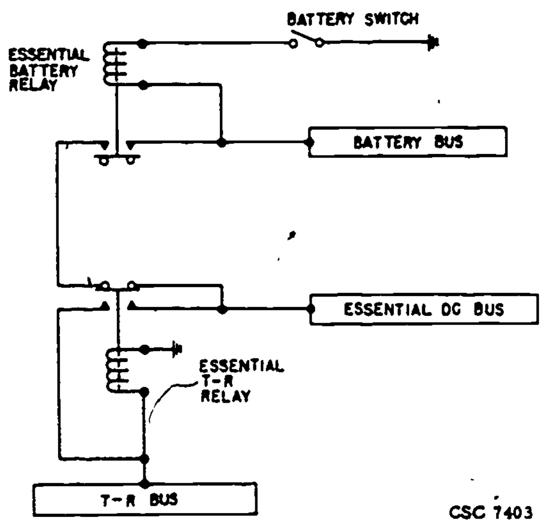

Figure 50. Essential dc T-R system.

ergized. Under this condition the bus tie will become energized and interconnect the T-R buses through current limiter Nr. 2, even though current limiter Nr. 1 might still be intact.

17-5. This concludes the discussion of T-R's and T-R power distribution systems, except for a brief discussion of an essential bus system in which T-R units are the primary source of dc power. On many aircraft, switching of power from one source to another is done automatically through a system of *essential relays*. Figure 50 illustrates a typical essential bus system using relays.

17-6. The essential T-R relay is energized any time there is power on the T-R bus. When the relay is closed, it completes the circuit to the essential bus. If the T-R bus is not powered, it is necessary to energize the battery relay and apply battery power to the essential bus. When both relays are energized, which is a normal condition, only one source of power can be applied to any one bus at a time.

17-7. **Maintenance.** The maintenance you can perform on a T-R unit is generally limited to the repair or replacement of subunits of the major assemblies. You may disassemble a T-R unit only to the extent authorized your shop; for example, you can completely disassemble a rectifier type T-R unit and repair or replace any of the major assemblies. When you disassemble the battery charging T-R unit, however, you are not allowed to open the transformer section. Another important point should be brought out at this time. Many components of the static T-R's and battery charging T-R's come in matched sets. If one part of a set requires replacement, you will have to install a whole new matched set. This is why it is important to consult the appropriate technical directive before you attempt to repair or replace any part of a T-R unit.

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AC Generator Systems

MOST OF today's aircraft use a great deal of ac power. Consequently, the primary power system used on present day aircraft is ac. This does not mean you won't find a number of aircraft still in the Air Force that have a primary dc power system. Chapter 3 provided you with the necessary background knowledge to work on dc power systems. In fact, you will be using your knowledge of dc generators in our discussion of an ac generator in this chapter.

2. Ac electrical loads, for the most part, require constant-frequency ac power. But always keep in mind, there are ac loads that do not require constant-frequency ac power. These loads are supplied power from variable-frequency ac generators, also discussed in this chapter.

3. There are many types of ac generator systems in current use. However, you will be able to grasp the general idea behind all of the various types, because they fall into two classifications, the variable- and the constant-frequency ac generator systems. We will discuss both of these systems in this chapter. The discussion of the variable-frequency system is limited due to its limited application. We will begin our discussion with the ac generator.

4. Foldout 2 shows a basic ac generator system of the type we will discuss in this chapter. The knowledge of the type of aircraft that may use this system is not a requirement for this discussion. This system is used only as a training vehicle.

18. AC Generators

18-1. The output of the ac generator must be held to a constant value over a given range of operation. In order to do this in a constant-frequency ac system, a voltage regulator and a constant-speed drive unit must be used. In a variable-frequency system, however, only the voltage regulator is used to provide a stable output over the generator's entire speed range of operation.

18-2. The following discussion deals with what takes place inside the generator under the various load conditions that are encountered in actual operation. This information provides you with the background knowledge required to troubleshoot, test, and repair ac generator systems. References are made to the various generator system components as they are affected by a given load condition. Let's start our discussion by reviewing the factors that affect the generator's output frequency.

18-3. **Generator Frequency.** Ac is produced when a coil is rotated between a north and a south magnetic pole. In such a device, the strength of the generated voltage depends upon the strength of the magnetic poles, the number of turns of wire in the coil, and the speed at which the coil is rotated. The frequency of the current pulsations depends upon the speed of coil rotation and the number of poles, but not upon the strength of the magnetic field.

18-4. Let's assume that a generator rotor is connected directly to the crankshaft of an engine. With this arrangement, the rotor makes one revolution every time the crankshaft makes one. Therefore, if the engine crankshaft is turning at a rate of 380 rpm, the rotor also turns at a rate of 380 rpm.

18-5. Remember, don't confuse the generator speed with its frequency. Since the speed of rotation is measured in revolutions per minute (rpm) and frequency is measured in Hertz (Hz), we need to use the frequency formula to determine the output frequency of the generator.

$$\text{Frequency} = \frac{\text{number of pairs of poles} \times \text{rpm}}{60}$$

Therefore, if there is one pair of poles in the generator and it is turning at a rate of 380 rpm, use the formula:

$$\text{Frequency} = \frac{1 \times 380}{60}$$

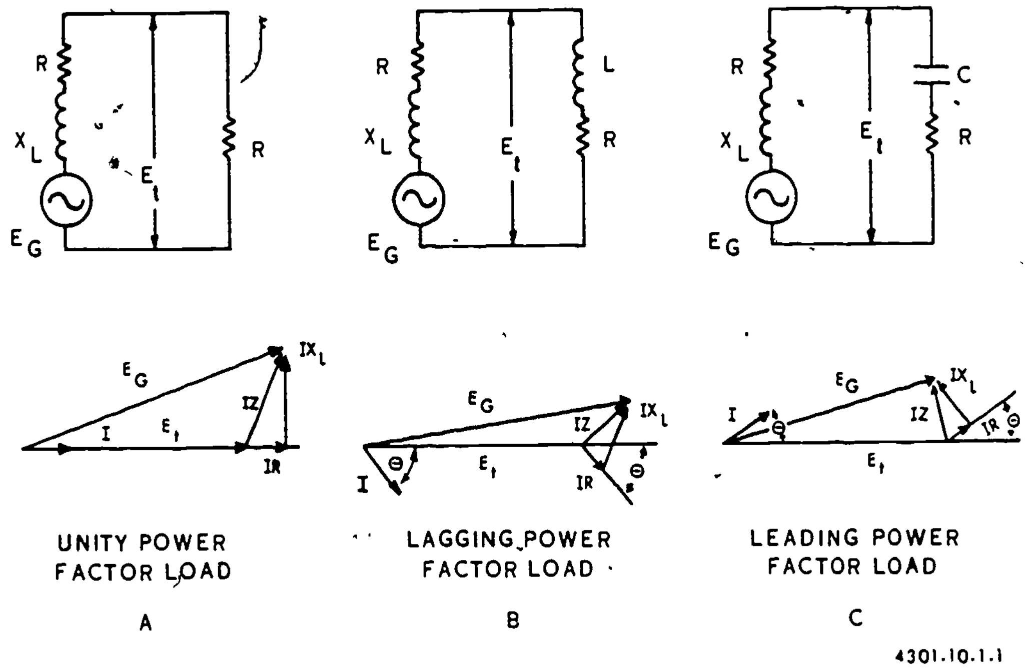


Figure 51. Generator voltage and load characteristics.

Thus,

Frequency = 6.33 Hz

18-6. It is necessary to have a gear train between the crankshaft and the rotor of the generator because the crankshaft of a reciprocating engine rotates too slowly for the desired voltage and frequency. Although a jet engine rotor turns at a faster speed than does a reciprocating engine, a gear train is still required. Since variable-frequency generators used by the Air Force generally incorporate a 12-pole field, the gear train is required to drive the rotor between 3800 and 10,000 rpm to produce the allowable frequency, 380 to 1000 Hz.

18-7. Although the frequency is allowed to vary, the voltage must be kept at a constant value. This is accomplished through the use of a voltage control circuit. A second point to keep in mind is that a variable-frequency generator can be used only in conjunction with resistance-type loads, because of the varying frequency. Since capacitive and inductive reactances vary with the frequency, it is not feasible to use inductive or capacitive loads in connection with variable-frequency generators.

18-8. On the other hand, a constant-frequency ac generator can be connected to all of the various types of ac loads, which include both KW and KVAR loads. This type of generator provides a constant output frequency (400 Hz), and therefore, the rotor must be driven at a constant speed. A device known as a constant-speed drive does this task. While the drive maintains the rotor speed constant, it must also vary its output (torque) to maintain the load on the generator. We will next discuss effects that various load conditions have on the generator output.

18-9. **Generator Load Characteristics.** When the load on the generator is changed, the terminal voltage of the generator will vary. The amount of variation depends on the design of the generator and the power factor of the load. With an inductive load, which has a lagging power factor, the drop in terminal voltage when the load is increased, is greater than would occur if the load had unity power factor, that is, a resistive load. With a load having a leading power factor, a capacitive load, the terminal voltage tends to rise. A change in terminal voltage with a change in generator load is due to the change in armature resistance, reactance and reaction.

18-10. *Armature resistance.* When current flows through a generator armature winding, there is an armature resistance drop (IR) due to the resistance of the windings. This drop increases with load, and the terminal voltage is reduced. (IR) is normally small because the resistance is low.

18-11. *Armature reactance.* The armature current of an ac generator varies approximately as a sine wave. The continuously varying current in the generator armature is accompanied by an $I \cdot X_L$ voltage drop in addition to the IR drop. Armature reactance in an ac generator may be

from 30 to 50 times the value of armature resistance because of the relatively large inductance of the coils as compared with their resistance.

18-12. A simplified series equivalent single-phase circuit of an ac generator is shown in figure 51. The voltage generated in the phase winding is equal to the vector sum of the terminal voltage, E_t, for the phase and the internal voltage loss in the armature resistance, R, and the armature reactance, X_L, associated with that phase. The voltage vectors for a unity power-factor load are shown in figure 51 (A). The armature IR drop is in phase with the current, I, and the terminal voltage, E_t. Because the armature $I \cdot X_L$ voltage drop is 90° out of phase with the current, the terminal voltage is approximately equal to the generated voltage, less the IR drop in the armature. In this case, the voltage regulator output changes very little. The only change will be to overcome the larger IR drop caused by the increase in load current.

18-13. All of this is true as long as rotor speed is maintained. The flux produced by the load current has an effect on the speed of the rotor. The load current produces a magnetic field which magnetizes the iron core (stator) in such a manner as to tend to keep the rotor from moving. To overcome this holding effect, more power, or torque, must be applied to the rotor to maintain the load at the same speed. Then for a real or KW load on the generator, we can see that the primary consideration is power (torque). Very little increase in regulator output is needed.

18-14. The voltage vectors for a lagging power factor (KVAR) load are shown in figure 51 (B). The load current and IR drop lag the terminal voltage by angle Θ. In this example, the armature drop (I) is more nearly in phase with E_t and the generated voltage (E_G). Therefore, the terminal voltage is approximately equal to the generated voltage, less the armature I drop. Because the I drop is much greater than the IR drop, E_t is reduced that much more. Why is this? The flux (magnetic field) produced by the load current is 180° out of phase with the magnetic field that produced it. Under these conditions, it is necessary to greatly increase the magnetic field inducing the voltage (E_G) in order to maintain generator output at preset value.

18-15. You can see for the condition above, there is no requirement to increase the torque applied to the rotor. Rather, the strength of the generator field excitation must be increased in order to maintain generator output at a constant value. Keep in mind, then, that the voltage regulator for the most part, determines the generator's ability to carry a reactive load.

18-16. The voltage vectors for a leading power-factor load are shown in figure 51 (C). The load current and IR drop lead the terminal voltage by angle Θ. This condition results in an increase in terminal voltage above the value of E_G. The total available voltage of the ac generator phase is the combined effect of E_G (rotationally induced) and the self-induced voltage (not shown in the vectors). The self-induced voltage, as in any ac circuit, is caused by the varying field (accompanying the varying armature current) linking the armature conductors. The self-induced voltage always lags the current by 90°; therefore, when I leads E_t, the self-induced voltage aids E_G, and E_t increases. Under these conditions, the field current would have to be decreased by the voltage regulator.

18-17. Also, due to a mechanical lag of the rotor, the stator current causes the pole shoes of the stator core to be magnetized so as to attract the rotor poles, thereby tending to pull it through as a motor. This condition also calls for a slight decrease in the torque required to drive the rotor.

18-18. It should be obvious from our discussion so far, that it is virtually impossible to apply a zero power-factor load to an ac generator, but just as obvious that almost all loads will contain a degree of reactance. The type of reactance normally encountered is inductive.

18-19. **Paralleling Requirements.** In order to improve the reliability and power capabilities of the aircraft ac electrical power system, constant-frequency ac generators are often operated in parallel. However, before ac generators can be safely paralleled, the following conditions must be met.

- The generators must be of like design.
- They must have equal terminal voltage.
- They must be of equal frequency.
- Their voltages must be in phase.
- Their phase rotation must be alike.

18-20. After the above conditions have been satisfied, the generators can be paralleled. However, to keep these generators operating in parallel, the torque of the drive unit as well as generator excitation, must be controlled.

18-21. The amount of real power delivered by any generator is determined by the real load (as mentioned in previous material) and the power delivered by the prime mover (drive unit). The reactive power requirements of a generator are determined by the reactive load on the bus and the excitation difference between generators. Paralleled generators which are equally excited and delivering the same output voltage, have no local currents circulating between them.

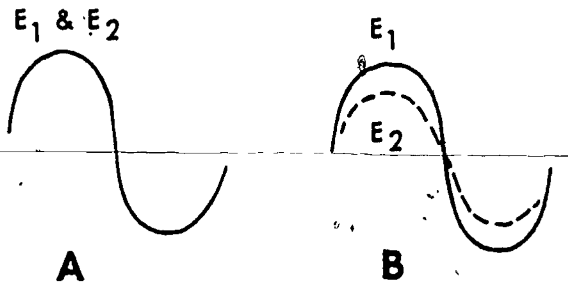


Figure 52. Generator output voltages (parallel operation).

18-22. In figure 52, the generators (A) are delivering the same voltage of the same polarity at the same time. Since the voltages are in phase, both in polarity and magnitude, each generator shares the load equally, and the generators do not appear as loads to each other. However, in figure 52 (B), the generators are in phase but unequally excited. Since a voltage difference exists, current is delivered from generator Nr. 1 to generator Nr. 2. Generator Nr. 2 presents a high inductive load. and the energy must be dissipated by the high-voltage generator. Later in this chapter, we will discuss in some detail load control between paralleled ac generators. At this point in our discussion, it is only important that you understand the various types of ac loads and their effect on the generator.

18-23. **Generator Rating.** The last point to consider in our discussion of generator principles is how the ac generator is rated. The rating of an ac generator pertains to the load it is capable of supplying. The normal load rating is the load it can carry continuously. Its overload rating is the above normal load which it can carry for specified lengths of time only. The load rating of a particular generator is determined by the internal heat it can withstand. Since heating is caused mainly by current flow, the generator's rating is identified very closely with its current capacity.

18-24. The maximum current that can be supplied by an ac generator depends upon (1) the maximum heating loss (I^2R power loss) that can be sustained in the armature, and (2) the maximum heating loss that can be sustained in the field. The armature current varies with the load. This action is similar to that of dc generators. In ac generators, however, lagging power factor loads tend to demagnetize the field, and the terminal voltage is maintained only by increasing the dc field current. When the power factor is low and a generator is delivering a power load within its rated capacity, the current may be far in excess of the rated capacity of the generator. Therefore, ac generators are rated in terms of armature load current and voltage output, or kilovolt-ampere (KVA) output, at a specified frequency and power factor.

18-25. **Variable-Frequency Generators.** The Air Forces uses various types of variable-frequency ac generators today, but for this discussion we will consider only the single-phase variable-frequency ac generator.

18-26. *Construction features.* Generators of the variable-frequency single-phase type are similar in appearance to the dc generator discussed in Chapter 3. The general appearance may vary with the manufacturer, but only slightly. However, we are interested in the internal construction, and for this explanation we shall examine a B–1 single-phase variable-frequencv ac generator.

18-27. The stator (see fig. 53), which is the stationary set of windings (F), includes 12 laminated pole shoes whose field windings are connected in series. These shoes incorporate damper segments which form a complete "squirrel cage" winding. Such construction affords a more even distribution of the field flux. The purpose of the damper feature is to provide a better waveform in the generator output voltage by smoothing out the field current pulsation produced by the exciter regulator.

18-28. The terminal block, figure 53 (E), is made of molded plastic and is mounted on the outside of the generator housing. The terminal block has four terminals, two for the field circuit and two for the ac output.

18-29. The rotating member of the generator is composed of the rotor windings (H), in which ac voltage is induced by rotation through the magnetic field produced by the field windings (F), and collector rings (I), which in turn provide a means of coupling the induced voltage to the output terminals of the generator. The rotor winding and collector rings are mounted on a shaft which is supported between ball bearings (A). A spindle (G) which mates directly to the drive unit or engine is coupled to the shaft by means of a splined coupling along with a friction shoe damper (J). The damper provides isolation from torsional oscillations which in turn reduces wear and prevents spindle breakage.

18-30. A laminated asbestos phenolic ring serves as a mount for two pair of brass brush holders (C). The carbon brushes (D) in the holders are held firmly against the collector rings by springloaded fingers. Cooling is provided by blast air through the blast tube (B).

18-31. *Generator operation.* Our discussion here is limited to a brief review of generator

operation. Variable-frequency generators are designed to operate at a given kva rating at speeds between 3800 to 10,000 rpm. These generators may be rotated either clockwise or counterclockwise, but the brushes must be reseated if the direction of rotation is reversed. Then, too, because of the variable frequency, these generators cannot be operated in parallel. Because collector rings are used, this type of generator should not be connected to heavy loads, for the brushes have a tendency to arc and spark under heavy-load current.

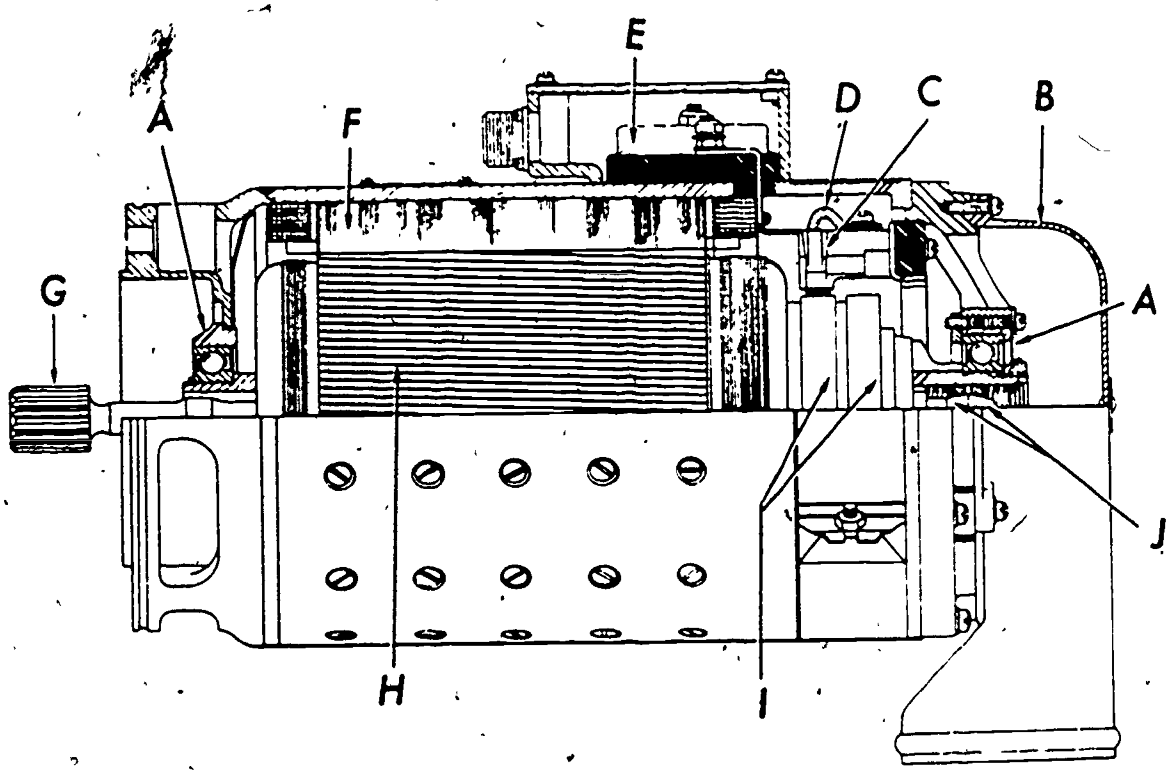
18-32. Close voltage regulation is necessary for the satisfactory operation of all electrical equipment. For the single-phase type B–1 ac generator, voltage regulation is achieved with an A–1 exciter-type regulator.

18-33. This exciter regulator is nothing more than a heavy-duty vacuum-tube rectifier. Such a unit takes power from the generator output and converts it into dc, which is sent through the generator field to magnetize the field poles. A bridge and a phase-shift network controls the regulator output to maintain a constant generator voltage output. Since the residual voltage of the generator is not high enough to operate the exciter regulator, current is taken from the aircraft's dc bus for initial excitation. In a sense, then, the generator is a self-excited unit except for the first few seconds, when power is taken from the aircraft's dc power distribution system for exciting current. If the generator speed falls below 3000 rpm, the exciter regulator ceases to function.

18-34. Keep in mind that only a KW load (real load) is applied to the variable-frequency generator. This type of generator is connected directly to the engine; thus, the torque requirements are automatically taken care of by the engine as load is increased or decreased. Very little change in regulator output is required as long as the speed remains the same.

18-35. When engine speed is changing, regulator output must also change to maintain a constant generator output voltage. In other words, exciter-regulator output will have a greater change with respect to changing speed than it will have with respect to changing load condition, provided the load range of the generator is not exceeded.

18-36. The voltage output of the B–1 variable-frequency generator is single-phase 115



A. BALL BEARINGS
B. BLAST TUBE
C. BRUSH HOLDERS
D. BRUSH
E. TERMINAL BLOCK
F. FIELD WINDING
G. SPINDLE
H. ROTOR WINDING
I. COLLECTOR RINGS
J. FRICTION SHOE DAMPER

Figure 53. Single-phase variable-frequency ac generator.

volts. Remember, there are some three-phase variable-frequency generators in use by the Air Force. The output voltage of these generators is the same as that of a constant-frequency three-phase generator, which will be discussed next in this chapter.

18-37. **Constant-Frequency Generators.** Most aircraft ac electrical equipment has been designed to operate from a constant-frequency source of ac power. Aircraft electrical equipment can be designed to operate at almost any given frequency. However, designers have agreed that electrical equipment required for use aboard aircraft will operate satisfactorily at 400 Hz. Designers have also found that aircraft electrical equipment designed to operate at 400 Hz stays well within the weight restrictions imposed on the design of such equipment.

18-38. There are two different types of constant-frequency generators in general use in the Air Force today. They are the brush type and the brushless type, either of which may be air cooled or oil cooled. In this discussion we will discuss both types of ac generators.

18-39. *Brush-type ac generator.* The A-1 ac generator is a revolving field type of generator. The salient points of this generator are shown in figure 54. In this generator, dc from an integral exciter generator is passed through windings on the rotor by means of sliprings and brushes. This maintains a rotating electromagnetic field of fixed polarity (similar to a rotating bar magnet). The rotating magnetic field, following the rotor, extends outward and cuts through the armature windings imbedded in the surrounding stator, thus inducing a voltage. Since the output power is taken from stationary windings, the output may be connected through fixed terminals directly to the external load. This is advantageous, in that there are no sliding contacts, and the whole output circuit is continuously insulated, thus minimizing the danger of arc-over.

18-40. Sliprings and brushes are still used on the rotor to supply dc to the ac generator field. They are adequate for this purpose, because the power level in the field circuit is much lower than in the armature circuit.

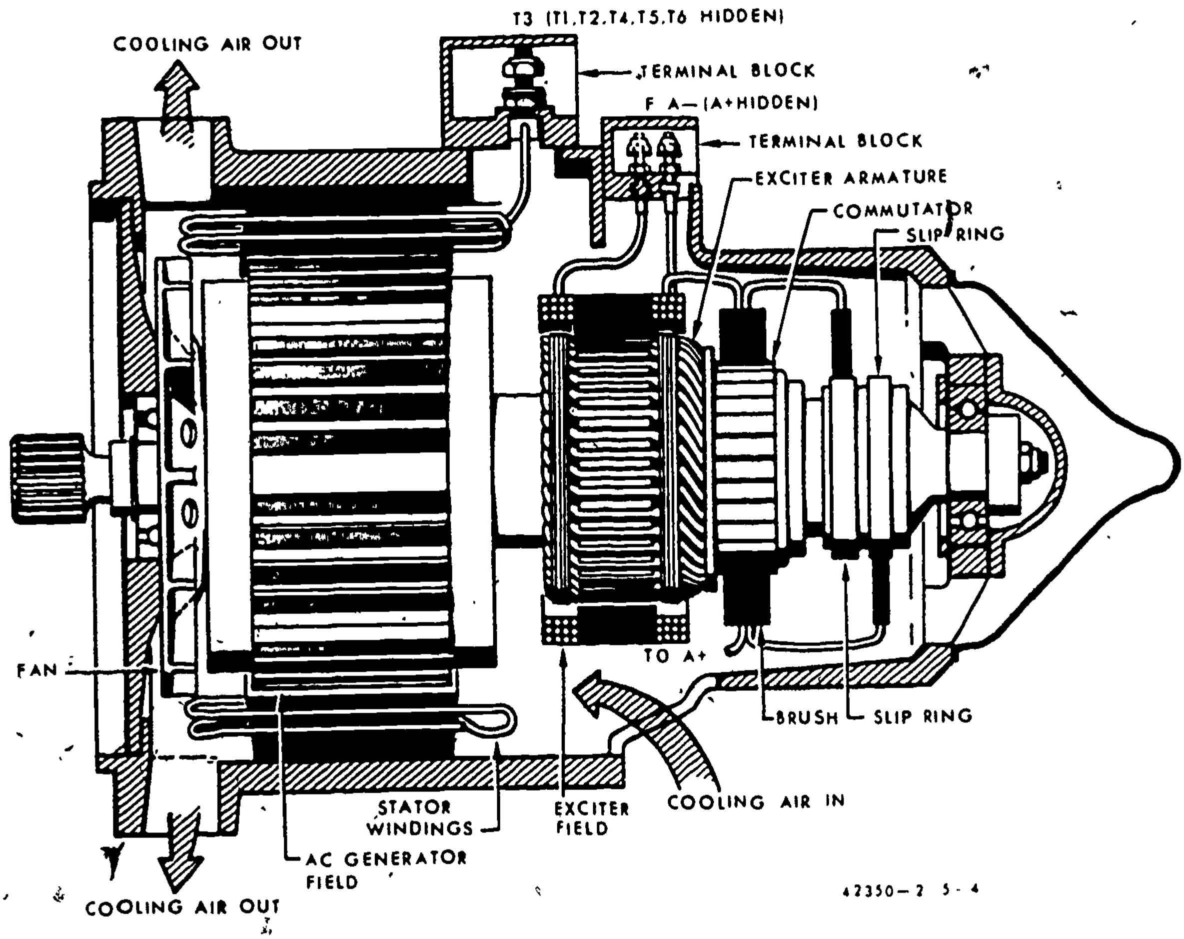


Figure 54. Type A1 generator cutaway.

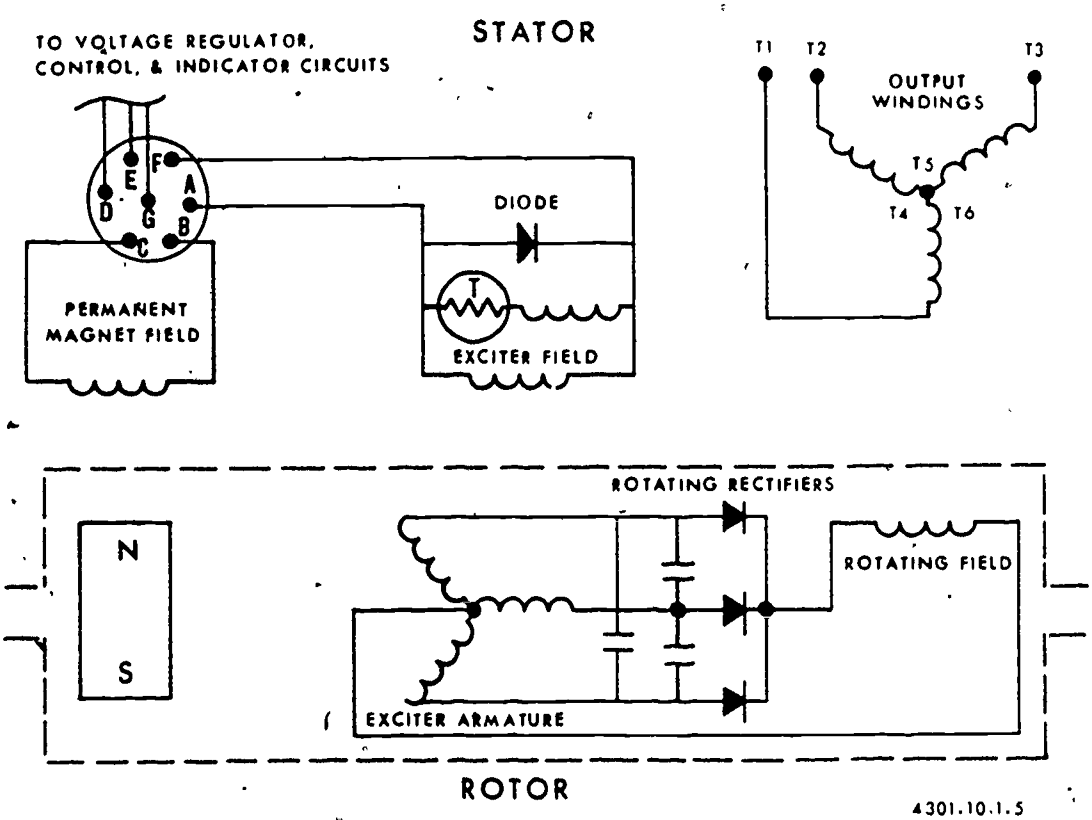


Figure 55. Brushless ac generator schematic.

18-41. *Brushless-type ac generator.* The brushless ac generator is one of the new units included on later model aircraft. The change to this type of generator was considered necessary because the newer aircraft fly at such high altitudes with much larger electrical loads. If you recall, brushes have been pointed out as a weak point of the generator system at high altitudes. With the design of the brushless generator, however, this trouble has been eliminated.

18-42. A brushless generator is really a 3-in-1 unit in that the final output is the result of two previous stages or sequences. In fact there are really three separate and distinct generators in the one unit. The first is a permanent magnet (PM) generator, the output of which energizes the field of an exciter generator through the voltage regulator. The output of the exciter generator energizes the field of the main generator. The output of the main generator is fed to and is controlled by the voltage regulator by controlling the strength of the exciter output.

18-43. Let us now refer to figure 55 for a discussion of operation of the brushless generator. This type of generator contains a permanent magnet generator. which provides the initial excitation of 4800 Hz single-phase power. Current produced by the PM generator is fed into the voltage regulator, which in turn is rectified and controlled by the voltage regulator and fed back through pins F and A to the exciter stationary field. This current, exciting the exciter field, in turn produces three-phase ac in the rotating exciter armature. This is then fed to the three-phase half-wave rectifiers where it is rectified to pulsating dc. This current excites the main rotating field where it sets up magnetic flux in the field poles. The rotating magnetic field, cutting conductors in the ac output windings, produces a three-phase ac output.

18-44. Some brushless generators have a compounding winding and a dampening winding in addition to the main exciter field. The excitation provided by the compounding winding is proportional to the load on the generator. The voltage induced in the dampening winding, by transformer action, is proportional to the rate of change of excitation. This voltage is used in a feedback circuit of the voltage regulator to stabilize the signal in the control system.

18-45. Inverse voltages and negative voltage spikes, which have an adverse effect on generator operation, are compensated for by including in the generator's three capacitors and a diode. The capacitors are placed in parallel with the output of the rectifier assembly and the ac generator rotating field. Their purpose is to suppress rectifier peak inverse voltage; thus preventing

damage to the rectifiers upon removal of short-circuit currents or maximum-load current. A commutating diode is installed in the rear end bell of the generator and is connected across the exciter field winding. The purpose of the diode is to eliminate or reduce the negative voltage spikes produced when the capacitor discharges after the generator control relay has been tripped, thereby preventing damage in the voltage regulator circuit due to high transient currents.

18-46. The brushless ac generators are cooled by either blast air or engine oil under pressure. This same oil is also used to cool the rotating rectifiers, lubricate the end bearings, and cool the generator windings.

18-47. Now that you are familiar with the construction features of the constant-frequency generators, let us discuss the operating characteristics of these generators.

18-48. *Generator operation*. You already know that an ac voltage can be induced in a stationary coil by rotating a magnetic field in the vicinity of the coil. Also, a generator can be constructed which has the field rotating. With such an arrangement, the entire load current can be taken from the stationary winding. Consequently, the total output current does not have to be carried through the brushes. However, brushes and sliprings are still used in many generators to apply a dc voltage to the rotating field. Actually, the power required to produce a sufficiently strong field is usually less than one-tenth the maximum output power of the generator. Therefore, this "rotating field" type of generator is usually found where fairly large loads are desired. Then, because of the low voltage and current value in the field circuit, you seldom encounter trouble with this machine.

18-49. Let's return to the simple two-pole generator for a moment. You will recall that one cycle of ac is produced every time north and south poles pass a coil of wire. In order to produce the required 400 Hz, a two-pole generator would have to operate at 24,000 rpm. As stated earlier, aircraft engines, including jets, do not approach this speed. Therefore, some way must be devised to attain 400 Hz. This is done with an eight-pole rotor. If you check with the frequency formula, you will find that such a rotor operating at 6000 rpm will produce a 400-Hz frequency, while some other generators have a six-pole rotor and must operate at 8000 rpm to produce 400 Hz. Its magnetic poles have a shaft arrangement that gives alternate north and south poles. Each pole has a coil of wire wrapped around it, and the coils are connected in series with each other. The free leads at each end are attached to one of the two sliprings which are mounted on the rotor shaft. With this type of construction, a variable dc may be applied to the rotor winding for controlling the magnetic field strength, which in turn determines the voltage output of the generator.

18-50. By wrapping three more coils, which overlap each other, around laminated iron pole shoes fastened to a circular steel housing, we form what is called the armature of the constant-frequency generator. Since these coils do not move, we shall refer to them as the stator windings.

18-51. These three separate coils are 120° apart. For this reason, three separate voltages are induced, 120 electrical degrees apart, when the rotor assembly is inserted in the stator assembly and is made to turn. Since each of the stator coils is known as a phase, the output of the stator winding is called three-phase voltage.

18-52. At this point it is necessary to tread upon some ground for which the trail has already been cut. We mentioned that polyphase ac is made possible by a special type of generator, the connections for which are either wye (Y) or delta (Δ). We showed how they were connected, and we compared them to each other. Now, we come down to the practical application of these connections.

18-53. You know that there are two ends to each phase winding, therefore, six ends protrude from the stator housing. In order to complete a path for current from the generator to the load and back, we must connect these six leads in either "Y" or "Δ." Let's start with the "Y" because it is one of the most commonly used.

18-54. First, turn to figure 56,A. In this schematic you see the three coils of the "Y", each having two leads which extend out through the stator housing. Connecting three similar leads together forms a path for current from any one of the three coils to the other two. This forms what is commonly referred to as the neutral or fourth wire (which could be the fuselage) in a three-phase system. Connecting a voltmeter between any one of the three open leads and this neutral, you can measure the voltage induced in each stator coil. In the three-phase generator used by the Air Force, this voltage reading should be 120 volts ac. Since each of the stator coils is called a phase winding, the voltage of one coil is called phase voltage. Now, if the voltmeter is placed between any two of the open or phase leads, you actually obtain a line voltage reading, which is the voltage of two of the coils instead of one. Because the coils are 120 electrical degrees apart, only one of them will be in full power at a time, while the others are at partial power. The combination of the two volt-

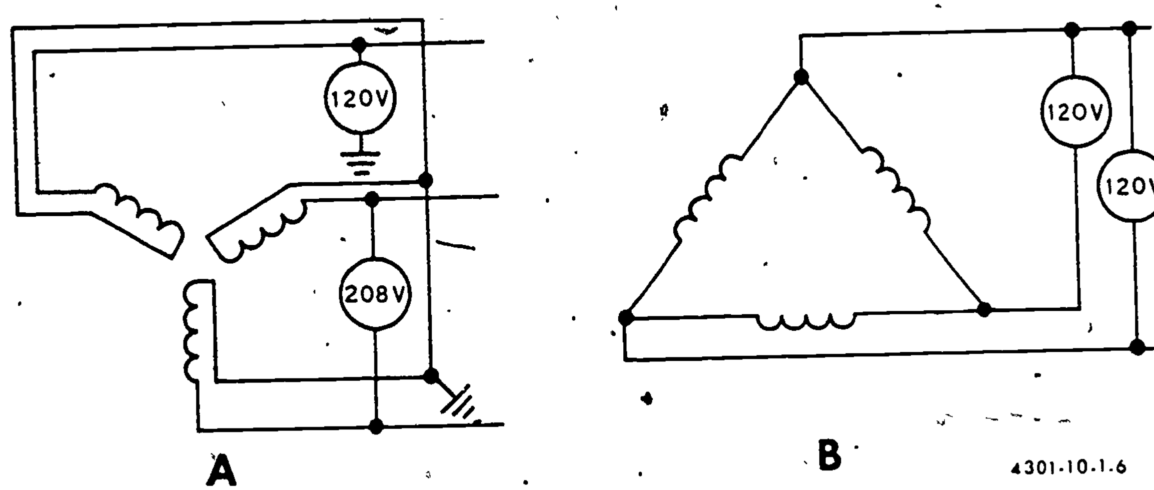


Figure 56. Wye and delta connections.

ages is 1.73 times greater than the voltage of only one coil, or 208 volts ac. It should be explained at this point that the voltage in the partially powered coils is in the same direction as the voltage in the fully powered coil. Thus, both are in series, which means that the voltage of the partially powered coils is added to that of the powered. Therefore, total generator output voltage is equal to the algebraic sum of the series voltages. The major advantage of a "Y" connection is that higher phase to phase voltages can be obtained.

18-55. On the other hand phase to phase voltage of the "Δ" connection is the same as its phase to neutral voltage because of the parallel connection of the stator coils. (See fig. 56,B). However, it can be put to good use for it has a higher current-carrying capacity than the "Y". Now, let's check and restate the major points concerning the "Δ" system. If the stator windings and the rotor magnetic strength are the same as those of the "Y" connection and you place a voltmeter between any two of the three protruding leads, you obtain the measurement of only the voltage of one coil or 120 volts. Inasmuch as there is no neutral or fourth wire in a "Δ" system, the phase and the line voltage are the same.

18-56. The generator is driven by a constant-speed drive unit, which in turn is driven by the aircraft engine. The drive unit is controlled by a frequency and load controller. A voltage regulator regulates the voltage output level of the generator, while a control panel protects the electrical system and components automatically when faults occur, by removing the generator from the bus. Both the voltage regulator and the frequency and load controller provide load division during parallel operation of the generators.

18-57. Load characteristics were explained earlier in this chapter. Recall that real load (KW) requires a change in torque output of the drive and that since this is a constant-frequency system, the speed must not change. Reactive load (KVAR) will require the exciter-generator field current to change with changing reactive load.

18-58. From our study of the generators you should understand that any change in generator load will require a change in both excitation and torque. You should keep in mind that the power output of the drive is proportional to the real load on the generator and that generator excitation is proportional to the reactive load on the generator. The complete generator system operation is discussed later in this chapter.

18-59. **Maintenance Requirements.** The detailed repair and overhaul of ac generators can be performed by a field maintenance activity or by a depot. Normally generators are not repaired by organizational maintenance. The extent of repairs that may be performed by a field maintenance activity are determined by the availability of special tools, test equipment, technical orders, parts, and skilled personnel. These resources must be made available before an effective overhaul can be performed at the field maintenance level.

18-60. *Generator maintenance, repair, and overhaul.* Before repairing or overhauling an ac generator, you must check the applicable technical order. This technical order contains a detailed step-by-step procedure for the task to be performed.

18-61. Normally the repairs performed by the field maintenance activity include: cleaning, inspecting, replacing of bearings, brushes, and the rotor assembly if it cannot be turned down on a

lathe to technical order specifications, and insulation breakdown testing of the windings and leads. When a kit is supplied for the repair of a generator, it will contain all the necessary parts for the repair.

18-62. It sometimes becomes necessary for a field maintenance activity to set up facilities to completely rebuild the ac generators because of either a shortage in supply or a high usage rate. In case the facilities must be set up, most of the required equipment, such as an oven for baking and drying insulation, special tools, and jigs, can be obtained through supply channels. It is not unusual for maintenance personnel to fabricate other special tools to accomplish this type of maintenance. This equipment, the repair kits, and skill all enable the field maintenance activity to turn out completely rebuilt ac generators of the highest quality.

18-63. Since there are numerous types and models of ac generators, we will not attempt to discuss the overhaul of a specific one. We do stress the importance of following the technical order for the unit. Special attention should be paid to the WARNINGS and CAUTIONS mentioned in the technical order. These points should not be overlooked when maintenance personnel are inspecting, repairing, or overhauling the unit. Neglect of these points could cause injury to personnel, damage to the unit, or even the loss of an aircraft and crew.

18-64. *Testing.* All ac generators that have been repaired or overhauled must be performance tested. This is done by mounting the generator on the appropriate test stand and conducting the tests outlined in the technical order. We have already discussed the ac generator test stand in detail in Chapter 2 of this volume.

18-65. The actual tests performed on each generator vary between generators. These tests generally include a method of checking stability of regulation at both minimum and maximum speed under no-load and full-load conditions. Immediately following these checks, and while the generator is still hot, a dielectric test is generally made. An insulation breakdown tester or a source of high-voltage ac, as specified in the technical order, can be used for this check. The dielectric test will point out possible insulation breakdowns that could occur when the generator reaches normal operating temperatures.

18-66. This concludes our discussion of ac generators. The next section is devoted to the generator drive which provides a means of turning the ac generator at a constant speed.

19. AC Generator Drive

19-1. In the first part of this chapter you learned that most aircraft having alternating current as the primary source of electrical power, use constant-frequency systems. That is, the frequency of the alternating current is maintained within the desired limits. It is necessary to have some mechanical means of turning the generator at a constant speed, regardless of any variation in engine speed or generator load.

19-2. Although you are responsible for only certain components of a generator drive, you must have a complete understanding of the principles of operation of each type of drive. This is because many of the troubles that occur in ac systems are caused by drive malfunctions, and you must know enough about the drives and their control systems to distinguish between drive troubles and system troubles. Also, the drive units have electrical control circuits for which you are responsible.

19-3 **Hydraulic Constant-Speed Drive (CSD).** The constant-speed drive is a hydraulic mechanical transmission that converts variable engine speed to a constant 6000 rpm output to drive a generator. The type CSD used to drive the 40-KV-A generator will be used as a model in the discussion. The input power to the unit is taken from the engine accessory section through a universal fitting. The ac generator, connected to the output of the drive unit, rotates at 6000 rpm. Although the CSD is a hydraulically operated unit, it is important that you understand the principles by which it operates. The discussion will begin with the main part of the drive, cylinder block assembly.

19-4. *Cylinder block assembly.* Figure 57 shows a schematic of a typical CSD unit. The cylinder block assembly consists of a piston-type, fixed-displacement motor. The pump and motor, which rotate within the case of the unit, are connected by a port plate, located between the motor cylinder and the pump cylinder, that allows the transfer of oil between the pump and motor. The variable-displacement pump unit consists of a pump cylinder block assembly and a pump wobbler assembly controlled by the drive governor system. Oil pressure supplied by the two charge pumps (also shown in figure 57) holds the pump piston rods against the pump wobbler, and stroking occurs when the cylinder block assembly is rotated. The pump unit volumetric displacement is varied by changing the angle of the variable pump wobbler plate. Changing the angle of the variable pump wobbler changes the reciprocating action of the pump pis-

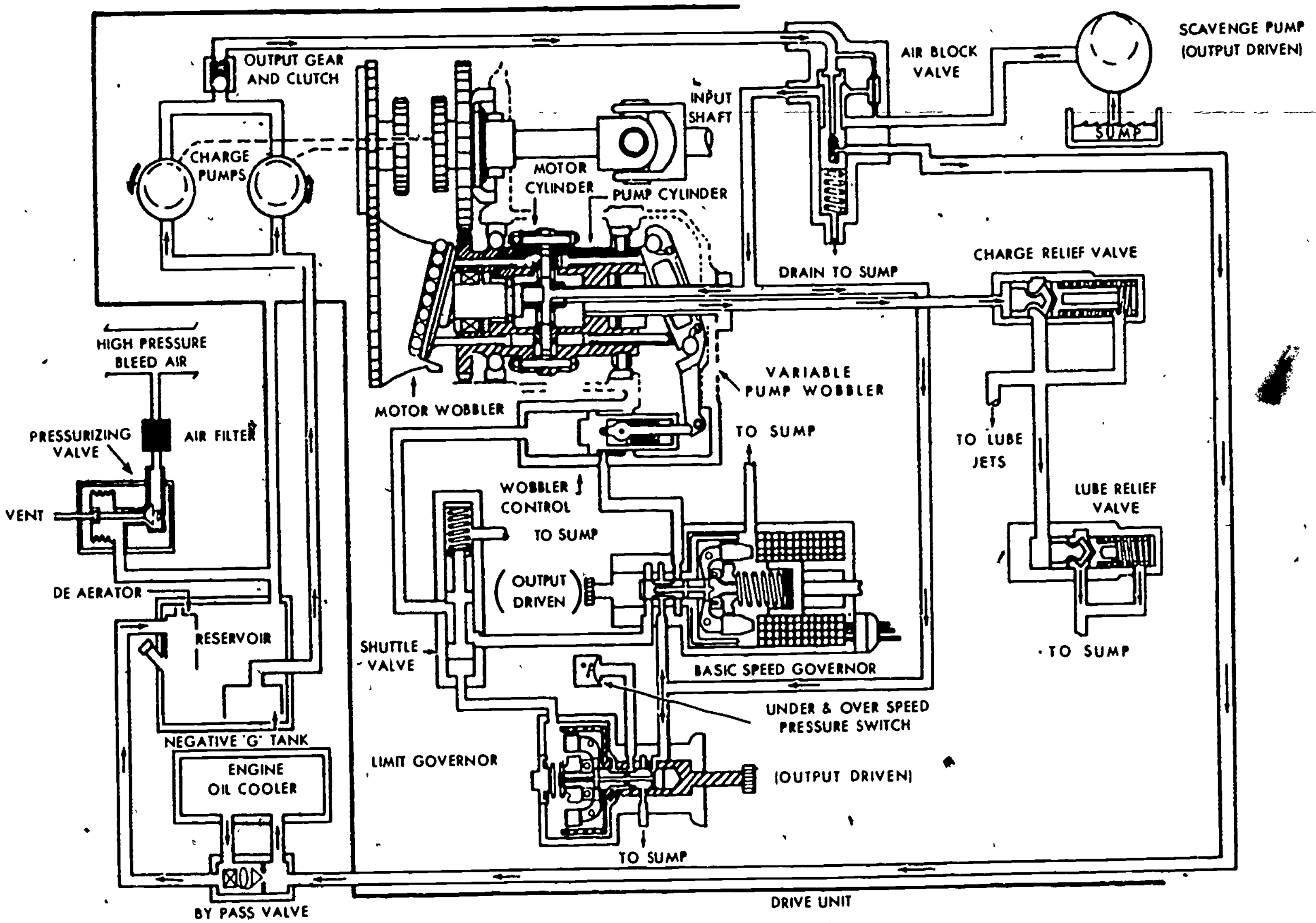


Figure 57. CSO schematic.

tons and causes the oil to be transmitted through the port plate to the hydraulic motor.

19-5. The fixed displacement motor unit consists of the motor block assembly and the motor wobbler plate. The oil pressure delivered through the port plate from the pump forces the pistons of the motor against the motor wobbler plate. The force the pistons exert on the wobbler plate is determined by the pump output; the greater the pump output, the greater the force exerted by the motor pistons against the motor wobbler as the cylinder block rotates. The motor wobbler, which is free turning, is connected to the output gear section to drive the generator. Thus, the linear piston action is converted to rotary motion.

19-6. Before you learn how the output of the drive is varied by changing the angle of the pump wobbler, let us discuss some of the conditions under which the drive operates. There are three distinct phases in the operation of the drive. One occurs when the drive is accepting input rotation and stepping it down. This is known as underdrive. Another occurs when the drive is accepting input rotation and stepping it up. This is known as overdrive. Another phase is straight through, when the input rotation drives the cylinder block at a rate that requires no modification. Now, let's examine each of these phases in detail.

19-7. *Underdrive.* When the pump wobbler is moved to the underdrive position, which is the position opposite to that shown in figure 57, the output speed of the motor wobbler becomes less than the speed at which the cylinder block is being rotated by the aircraft engine. The angle that the pump wobbler now assumes is such that the ratio of displacement of the motor is greater than that of the pump. In this condition, the pump ceases to supply working pressure to the motor. This allows the motor pistons to stroke under the influence of the reactive torque (load) of the generator, and oil is displaced to the pump. The motor wobbler is then driven at a slower speed than the cylinder block.

19-8. *Overdrive.* When the cylinder block rotation is below the required 6000-rpm output, the pump wobbler assumes an overdrive position, as shown in figure 57. With the pump wobbler in this position, the displacement of the pump pistons is greater than the displacement of the motor. Pumping of oil then takes place from the pump to the motor, and the reciprocation of the motor pistons exerts a positive thrust upon the face of the motor wobbler plate. This thrust forces the wobbler to increase its rotation above the rate at which the cylinder block is being rotated. In this way, the linear thrust of the pistons is translated into additional rotary motion of the wobbler, and the output rotation exceeds the input rotation. In this manner, the transmission—by hydraulic action—adds to the input rotation speed.

19-9. *Straight-through drive.* When the input to the transmission equals the desired 6000-rpm output, the pump wobbler assumes a straight-through drive position. This angle is such that, neglecting piston blowby, there is no reciprocating of the pistons and no displacement. In this phase, rotary motion is transmitted through the transmission without gain or loss, and is simply a coupling between the aircraft engine and the generator.

19-10. Now that you are familiar with the operation of the cylinder block assembly, let us see how the pump wobbler is moved in response to changing speed conditions. We have stated that the angle of the pump wobbler is controlled by the drive governor system. We will now discuss the drive governor system.

19-11. **Drive Governor System.** The governor system has two functions: (1) to control the drive output speed, and thereby the generator frequency; and (2) to equalize the load between generators operating in parallel. The drive governor system consists of the wobbler control, the basic speed governor, as shown in figure 57, and the unit known as a frequency-and-load controller (not shown). The arrangement and operation of these units make it possible to accurately control the angle of the pump wobbler, and hence to control the output speed of the drive.

19-12. *Wobbler control.* The wobbler control shown in figure 57 operates in conjunction with the basic speed governor to position the pump wobbler in response to speed changes.

19-13. *Basic speed governor.* The basic speed governor is a spring-biased, flyweight-type governor. It is driven from the output gears of the drive and senses variations from the desired 6000 rpm. When the output speed increases, centrifugal force causes the flyweights to move farther apart, and when the speed decreases, the flyweights move inward. The flyweight assembly is connected to a piston that meters oil to either side of the wobbler control. As oil is metered to either the underdrive or overdrive side of the wobbler control, the pump wobbler angle is changed. In this manner, the governor responds to speed and load variations and produces a constant output speed.

19-14. The term "basic speed governor" is derived from the fact that the metering piston that directs oil to either side of the wobbler control is spring-biased so that it establishes a basic generator frequency of 395 Hz. In this manner, if electrical control of the drive is lost, the system will drop to 395 Hz. Since 395 Hz is only a

reference frequency, some means must be provided to adjust and maintain the frequency at the desired 400-Hz point. This is the purpose of the frequency-and-load controller. The frequency-and-load controller is a device that senses deviations from the desired frequency and the amount of load on the generator, and adjusts the basic speed governor so that the pump wobbler is positioned at the correct angle to maintain the output of the drive within the desired limits. The operation of the frequency-and-load controller will be discussed in greater detail later in this volume, but for the present, we shall discuss the various means provided to adjust the basic speed governor to maintain the desired 400-Hz frequency.

19-15. Some models of the constant-speed drive use a precision frequency control motor to mechanically adjust the basic speed governor in response to signals from the frequency-and-load controller. The motor is a two-phase induction type, connected to a gear arrangement that repositions the metering piston of the basic speed governor as necessary.

19-16. The drive shown in figure 57 adjusts the basic speed governor magnetically. In this basic speed governor, the flyweights are alnico slugs soldered to the shoe of a standard flyweight. A trim coil is mounted in the governor head directly above the flyweights. The coils receive signals from the frequency-and-load controller and magnetically trim the speed of the drive by adding to or subtracting from the centrifugal force of the flyweights.

19-17. Now that you are familiar with the normal operation of the drive, we shall turn to some of the abnormal operating conditions, such as overspeeding and underspeeding.

19-18. *Limit governor.* The limit governor is the second of the two flyweight governors (see fig. 57). It is a protective device, and it serves two purposes; it places the drive in a full underdrive condition, in case of an overspeed or underspeed of the output; and it automatically removes the generator of that particular drive from the load. The units concerned with protecting the drive from over/under speed conditions are the limit governor, the underspeed-and-overspeed pressure switch, and the shuttle valve. These units, in conjunction with the basic speed governor, control oil pressure to either side of the wobbler control. To understand their operation, let us assume that the drive is in an overspeed condition.

19-19. *Overspeed.* The drive is considered to be in an overspeed condition when its output speed is in excess of approximately 7000 rpm. In normal operation (6000 rpm output range), the limit governor and the shuttle valve have no effect on the system. Although the flyweights rotate, they do not exert enough force on the metering piston inside the limit governor to overcome the spring tension exerted on the piston. The only effect of the governor is that the metering piston moves far enough to allow oil pressure to operate the underspeed-and-overspeed pressure switch. When the underspeed-and-overspeed pressure switch is actuated, it allows the generator to be connected to the aircraft bus system. This will be discussed in greater detail later in this volume. For the present, it is enough to know that when the pressure switch receives oil pressure, the generator output can be used; and when the underspeed-and-overspeed pressure switch is not receiving oil pressure, the generator is de-excited and has no usable output. Also, under normal conditions, the shuttle valve is in such a position that it allows oil pressure to be ported to the overdrive side of the wobbler control. Now, let's see what happens when the drive goes into an overspeed condition.

19-20. As the speed of the drive increases above approximately 7000 rpm, the flyweights of the limit governor move farther apart and adjust the metering piston to a position which allows the oil supply to both the shuttle valve and the pressure switch to drain into the sump of the drive. When the oil is drained from the shuttle valve, the spring inside the shuttle valve forces the valve stem downward. This action effectively shuts off the oil supply to the overdrive side of the wobbler control and also drains the remaining oil out of the overdrive side. Now, the oil supplied through the limit governor forces the wobbler control into the maximum underdrive position (negative angle), and the drive starts to slow down. At the same time, when the oil pressure was drained from the pressure switch, the generator was de-excited and that generator was removed from service. A shutdown caused by an overspeed condition is an irreversible process, because the charge pumps will maintain enough pressure to keep the shuttle valve in the down position and the pump wobbler remains in the maximum underdrive position. The limit governor metering piston is also held in a position that prevents oil pressure from entering the pressure switch, and thus the generator cannot be put back into service. The drive cannot be recycled until the engine has completely stopped.

19-21. *Underspeed.* The drive is considered to be in an underspeed condition when the output speed drops below approximately 4500 rpm. Under this condition, the limit governor flyweights move farther in, and (as in an over-

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speed condition) the shuttle valve stem moves down, the oil is from the overdrive side of the wobbler control, the pump wobbler moves to a negative angle, and the oil is ported from the underspeed-and-overspeed pressure switch. The only difference between an overspeed shutdown and an underspeed shutdown is that in an underspeed shutdown the drive can recycle itself if the speed is brought back to normal. Oil pressure will not hold the shuttle valve in the down position, nor will the port to the pressure switch be blocked if the output speed becomes normal again. The drive and generator can be returned to operation if the drive shuts down because of an underspeed condition, but cannot be used again in flight if the drive has shut down because of an overspeed condition. There are a few more features of this drive that we should discuss before we can discuss other types of generator drives.

19-22. *Overrunning clutch.* The clutch is a one-way device through which the generator connects to the output gear section of the drive. It is a sprag-type unit that prevents an overrunning or motorized generator from damaging the drive. As long as the drive is turning the generator, the clutch is engaged. If, for some reason, the generator is being motorized, or is turning faster than the drive, the clutch is disengaged and allows the generator to run free.

19-23. *Decoupling.* Some late model drives have decoupling circuits that enable the input to the drive to be completely disconnected from the aircraft engine if a drive malfunction occurs.

19-24. The typical CSD we have just described is designed to operate a 40-kva ac generator. This drive can best be described as a "linear" drive to distinguish it from a newer type of CSD that uses radial type pumps.

19-25. *Drive maintenance.* Only limited repair of a constant-speed drive is authorized at field level. If your shop does not have the basic field test stand, no attempt should be made to repair any of the drive components.

19-26. The main housings of the drive should not be opened under any circumstances. Internal servicing of the CSD requires controlled environmental conditions, and special test equipment and tools not generally available to your shop. Only those parts listed in the replacement parts chart of the technical reference for the particular drive on which you are working should be removed and replaced or repaired. You will usually find that repairs will be limited to such items as oil filters, pressure switches, external plumbing, and—in some cases—governor assemblies.

20. AC Generator Control System Components

20-1. In this section you will learn the various control and protective devices that make up a constant-frequency ac generator system. Foldout number 2 shows a complete generator control system with the necessary control components.

20-2. A complete and thorough knowledge of how these components operate is vital to the successful performance of your job as an aircraft electrician. For example, you will often be required to perform an operational check of a generator system. If you don't know how the system operates under normal conditions, you can see that it would be very difficult to detect any abnormal conditions. It is not enough that you know that a drive unit is used with a constant-frequency system, or that a certain type of voltage regulator is used with a certain generator. You must have an intimate, working knowledge of how these units operate, when they operate, and what effect they have on a system when they do not operate.

20-3. **Frequency and Load Controller.** There is a frequency and load controller for each generator. It senses the real load deviation (both magnitude and direction) from the average real load shared equally or balanced among the generators operating in parallel. The controller supplies a signal to the speed governor setting, on the generator drive, to correct any deviation of the generator from the average load.

20-4. The controller senses the generator frequency through a frequency discriminator circuit and controls the drive from the output of the magnetic amplifier section. The real load is sensed by the current transformer assembly which is attached to T3 on the generator feeder line, as shown in figure 58. The current transformer assembly is part of a load-division loop between generators operating in parallel. The load-division loop may be interconnected for parallel operation through the bus tie and generator breaker contacts. On some aircraft the controller load input signals are balanced by interconnection of the signal input circuits, while on others they are interconnected through an equalizing loop. Any real load unbalance between the generators is sensed by a network of current transformers, which is also known as the load-division loop, and will produce currents in the equalizing circuits which cause the controllers to reposition the frequency control on the drives in a direction to correct the load unbalance. Thus, each controller has two circuits, (1) the frequency control and (2) the load control. These circuits operate through a magnetic amplifier to control the fre-

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quency of their respective generators and divide the real load between paralleled generators. Let's follow the schematic in figure 58 and discuss how the controller functions.

20-5. *Load-control circuit.* A reference voltage for load sensing is provided at the output of a load-control circuit. The source of this voltage is the excitation winding (terminals 1 and 2) of the magnetic amplifier which is connected to T3 of the generator output and to ground. An auxiliary power winding then supplies an ac voltage to diodes CR1 and CR2, from terminals 12 and 15, with the circuit being completed through terminals 13 and 14. The load control circuit, made up of CR1, CR2, R2, R3, R10, and C1, provides a dc signal whose magnitude and polarity are dependent upon the magnitude and polarity of the current-transformer load-loop signal. This signal is impressed on resistor R13.

20-6. In operation, R10 is adjusted so the load-control circuit provides zero output when no signal appears on R13. The ac signal from the current-transformer load-division loop enters the load-control circuit across R13 and R15. These two resistors form a voltage divider circuit. When the ac signal of R13 is in phase with the voltage on T3 of the generator, it adds to the voltage across one resistor and the same side of R10 and subtracts from the voltage across the other resistor and the other side of R10. The situation is reversed when the ac signal on R13 is out of phase with the voltage on T3 of the generator. The net voltage across R2, R3, and R10 is the difference between the opposing voltages on the upper and lower halves. Thus, the resultant voltage will increase as the generator load unbalance increases, and decrease as the generator load unbalance decreases. This voltage is then applied to a compensation network. This is a lead-lag circuit composed of C2, C3, C4, R4, R5, and R6. The purpose of this circuit is to improve the response of the system to sudden changes in generator load and to boost the gain of the controller when the error signal is small.

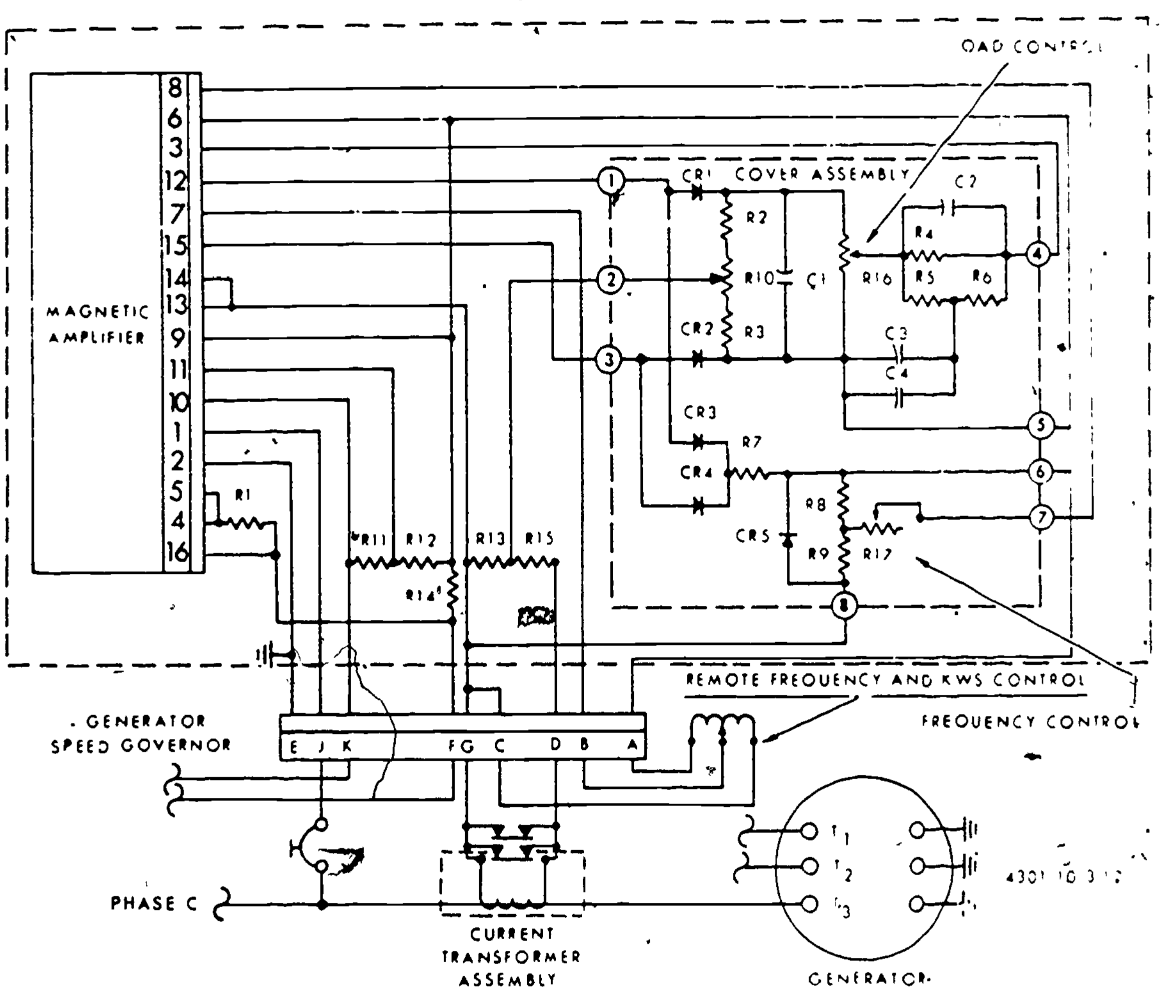

Figure 58. Frequency and load controller.

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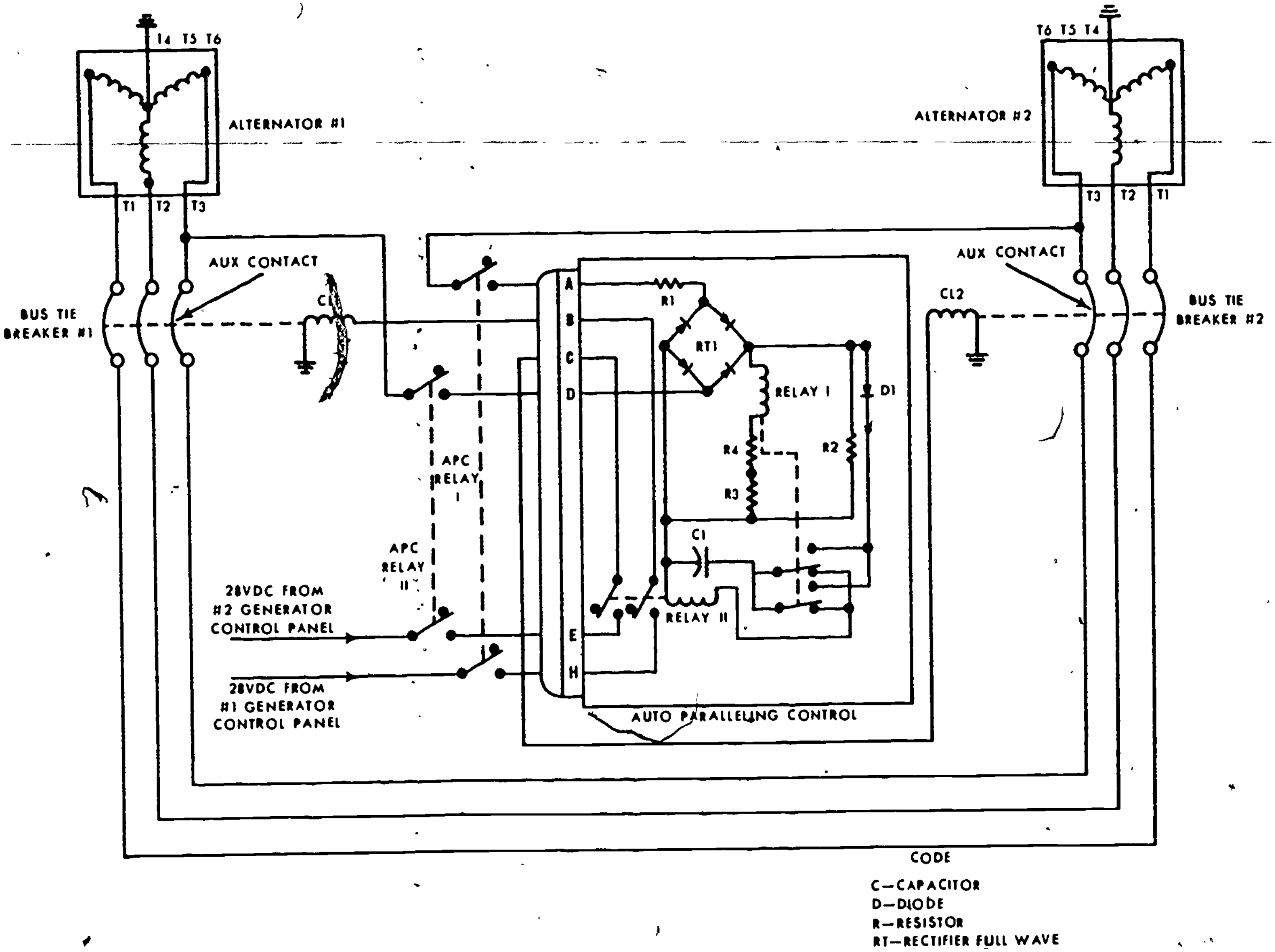

Figure 59. Automatic paralleling unit.

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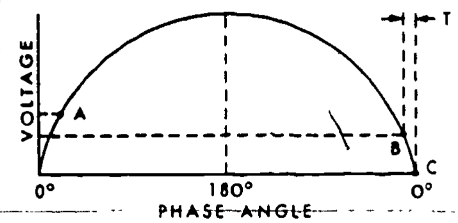
This prevents oscillatory motion or "hunting" of the speed governor in response to large error signals, and insures rapid corrective action when the error signals are small. Resistor R16 can be adjusted to vary the steady-state gain on the controller. The output of the compensation network is applied to a control winding (terminals 3 and 6) of the magnetic amplifier. The magnetic amplifier boosts this dc signal and produces a dc output which is applied to the trim coil of the generator speed governor. The magnitude and polarity of this output are dependent upon the magnitude and polarity of the dc input. The output of the magnetic amplifier appears across the generator speed governor and resistors R11 and R12.

20-7. *Frequency control circuit.* During normal operation an ac voltage from the auxiliary power winding is applied to a full-wave rectifier circuit consisting of CR3, CR4, and R7. The resulting pulsating dc voltage is then impressed across R8, R9, R17, and the remote frequency and real load control. This circuit forms a bridge which makes it possible to apply a dc signal to a control winding (terminals 7 and 8) of the magnetic amplifier. This signal, in turn, provides a bias voltage to the trim coil which may be varied with the frequency control potentiometer. The effect of this bias is to control the frequency of the generator output.

20-8. **Automatic Paralleling Unit.** The auto parallel unit automatically controls closing a selected generator breaker for paralleling operations. The phase "A" voltage of the incoming generator (unit selected) and the phase "A" voltage of the generator(s) on the bus tie are compared by a phase sensing circuit in the auto parallel unit. When the two voltages are in phase, a relay in the auto parallel unit closes the generator circuit breaker to parallel the machines. Under steady state conditions of load and input speed, the drive maintains the generator frequencies at 400 $\pm$ 1 Hz if the frequency and kws control on the electrical control panel is at its mid point of travel. The frequency and kws control provides a generator frequency variation of $\pm$ 2 Hz. The auto parallel unit will operate only if the generators to be paralleled are slightly out of phase.

20-9. The frequency difference between the generators must be two cycles per second or less. Therefore, it may be necessary at times to reposition the frequency and kws control to bring the two generators to within two cycles per second. When there is no voltage on the bus tie, the auto parallel unit does not affect control of the generator breaker due to auto parallel control relay action. The control relay transfers generator close coil control between the generator breaker switch and the auto parallel unit. The relay is energized by power from the bus tie through the "VOLTMETER—SYNC LIGHT—FREQ METER" circuit breaker on the main ac power panel.



A. POINT WHERE RELAY #1 ENERGIZES
B. POINT WHERE RELAY #1 DE-ENERGIZES
C. OPTIMUM PHASE ANGLE FOR PARALLELING
T. DELAY TIME OF RELAY #2 PLUS CIRCUIT BREAKER

Figure 60. Time curve.

20-10. Now let's take a look at how this is accomplished. The automatic paralleling unit is connected in the generator control circuit as shown in figure 59.

20-11. The paralleling circuit works at a maximum difference frequency of 4 cps between the two ac generators. A full-wave rectifier is connected to the same phase on each ac generator output. The output of this rectifier is connected to relay I. The voltage between the two phases depends on the phase angle between the two phases. At a difference of 180° the voltage will be at its maximum, twice the phase voltage. When the phase difference is zero degrees, the voltage difference will also be zero. As this voltage rises, the output voltage of RT1 rises (see fig. 60). Relay I actuates (point A) and connects capacitor C1 in series with diode D1 across the rectifier. C1 in charges through D1 to the maximum voltage across the rectifier. D1 prevents C1 from discharging during the time the voltage is decreasing from the peak value to point B. When the voltage output of the rectifier drops sufficiently (point B, fig. 60), relay I deenergizes and C1 discharges through relay II. Relay II actuates and causes the dc voltage at pins E and H to be connected to pins C and B of the APU. This dc voltage is applied to circuit breakers which parallel the generators. R2 protects rectifier RT1 by limiting the current through the rectifier. R3 and R4, when properly jumpered, permit relay I to actuate at the correct phase difference. The delay time (T) indicated in figure 60 allows relays I and II sufficient time to act before the generators are to be paralleled.

20-12. **Mag-Amp Voltage Regulator.** A mag-amp voltage regulator operates on the principle

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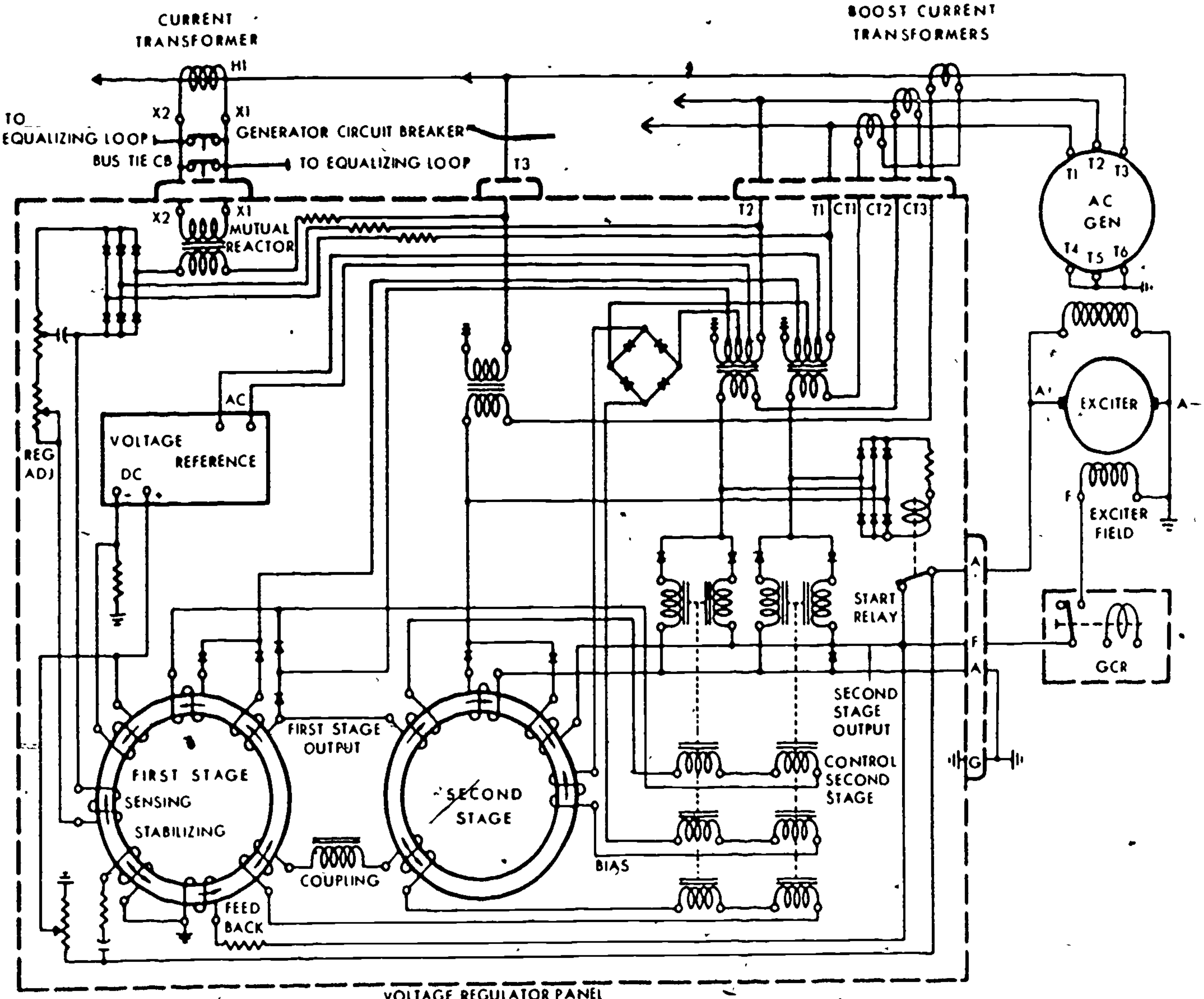

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Figure 61. Mag-amp voltage regulator.

of a saturable reactor. You will recall that we discussed magnetic amplifiers and saturable reactors earlier in the course. Now you will see the practical application of what you have already learned.

20-13. **Regulator Operation.** A typical mag-amp voltage regulator is shown schematically in figure 61. This is a closed-loop voltage regulator system, and the sensing circuit supplies a signal proportional to the average of the three line voltages to a dc control winding (sensing circuit of fig. 61). The voltage regulator, through its control circuits and its output to the exciter shunt field tends to minimize any error, attempting to keep the generator output voltage constant. This signal is compared magnetically to the reference signal (the reference signal is constant over a large range of generator output) in the first-stage magnetic amplifier. The resultant value of magnetic flux of the reference signal and the sensing signal is called generator error, and this error controls first-stage output. The output of the first stage is used to power the control winding of the second stage and thereby control second-stage output to the shunt field of the exciter generator. The first-stage magnetic amplifier uses additional windings which assist in the control of the output circuit.

20-14. The first-stage output is fed into a second-stage dc control winding, which is compared to a bias signal. The bias circuit is very similar to the reference circuit, except that the bias circuit signal is variable and is proportional to the line voltage. The magnetic resultant bias and the first-stage output signals control the second-stage output voltage. The second stage is called the power stage, and it supplies the dc power to the exciter field. The amount of dc power (excitation) supplied to the exciter, controls the level of output voltage of the ac generator.

20-15. To maintain a stable system, a feedback network, as shown in figure 61 is necessary. This circuit takes a rate-of-change signal from the exciter output voltage, A+ to A−, and feeds it into a control winding of the first stage. This signal is in such a direction as to oppose any change which occurs due to transient load conditions.

20-16. In order to obtain output power for the exciter field from the voltage regulator, ac generator output is required as the input power to the voltage regulator. A starting relay is used to permit generator buildup without voltage regulation. This is accomplished by using normally closed circuits connected from A+ to F through the generator control panel. This allows the generator exciter to use self excitation to build up the ac generator voltage so that the power is available for use in the regulator. As soon as the ac generator builds up to 195 volts line-to-line, the start relay contacts are opened. This, then, allows the voltage regulator to take control of the system.

20-17. Boost current transformers, one located on each phase lead (see fig. 61) and connected to the regulator through terminals CT1, CT2, and CT3, are used to boost or compound the regulator output during overload and short-circuit conditions. The rated voltage output of the generator is required under all conditions, including that of overload. The boost current transformers increase the regulator maximum output limit by increasing the voltage supplied to the second-stage magnetic amplifier output circuit. When the system is operating at rated voltage, the regulator controls the excitation to the exciter field as required to maintain the system voltage constant. The boost current transformers are used only to extend the maximum output limit of the regulator. During three-phase short-circuit conditions, the voltage drops to a low value, outside the limits of the voltage regulator. When this occurs, there is no control of the ac system except by the boost current transformers which are designed to supply the rated short-circuit current. Three-phase short circuits are primarily controlled by the design of the boost current transformers and the generator. The voltage developed across the boost current transformers during three-phase short circuits maintains the voltage on the starting relay coil so that the contacts remain open when the line-to-line voltage drops below relay-closing voltage and thereby prevents the voltage regulator from cycling.

20-18. Under varying load conditions, the generator winding temperatures increase and consequently cause generator losses to increase due to the increased resistance. In order to maintain very closely regulated voltage, a trimming circuit or positive feedback circuit is used. This circuit senses the exciter output voltage from A+ to A−. A resistor is added to the feedback circuit so that the circuit boosts the regulator output when required at loads of 50 percent and above.

20-19. When several generators are operating in parallel, the voltage regulators function to control the division of reactive load (KVAR), and they have only a negligible effect on the division of real load (kw). As you know, real-load division is controlled by the speed governors of the generator drives.

20-20. A current transformer, (see fig. 61), whose primary is the power lead (T3) from the generator, has its secondary connected to X1 and X2 on the regulator, which in turn is con-

nected to the mutal reactor in the sensing circuit of the voltage regulators. It is essential that the current transformers be connected exactly as shown and that it be placed on the power lead T3 (C phase) with the H1 end of the transformer directed toward the generator. The X1 and X2 terminals of the current transformer are connected into an equalizer loop (fig. 61), which is a series-parallel loop with the X1 terminals of one current transformer connected to the X2 terminals of the current transformer of the next generator in the parallel system. The diagram shows that one of the auxiliary switches of the generator circuit breaker is connected to short circuit terminals X1 and X2 of the current transformer when the circuit breaker is open. Thus, a generator-regulator unit that is disconnected from the bus will not affect the regulated voltage in the rest of the ac system.

20-21. **Regulator Control.** The performance of any regulator depends on the performance of the various subcontrol circuits located within the regulator. We will now discuss these individual circuits and their operation.

20-22. *Reference circuit.* The reference circuit in this regulator supplies a constant output dc which is used as the name infers. This reference is a completely static device which is not sensitive to normal operating frequency changes and normal voltages changes. If, during normal operation, the references signal (34 to 38 milliamperes) is lost for any reason, the voltage regulator output will go to minimum. When this happens, the system voltage will cycle because of the opening and closing of the starting relay contacts as the system voltage rises and falls. The system voltage will go to approximately 200 volts and then fall off to 100 volts, cycling at a frequency of 5 to 10 Hz.

20-23. *Sensing circuit.* The sensing circuit applies a 57-vdc signal, proportional to the average of the three ac phase-to-phase voltages, to a control winding of the first-stage magnetic amplifier. This signal is in such a direction as to oppose the signal supplied by the reference circuit, and tends to drive the first stage output to minimum. If, for any reason, the sensing signal (28 to 35 milliamperes) is lost, the regulator output goes to maximum forcing the output voltage of the system to go to maximum, which is approximately 300 volts at 400 Hz with no load on the generator. Faulty rectifiers in this circuit usually cause the voltage level of the system to go high, since they decrease the dc output signal.

20-24. *Power transformers.* The power transformers provide the power required by the regulator. The primary power of the power transformer is wye-connected with all three phases tapped. T1 is tapped at 70 volts line-to-ground (neutral) to supply the voltage for the second-stage bias circuit. T2 is tapped at 30 volts phase-to-ground to supply the ac power for the first-stage magnetic amplifier. T3 is tapped at 120 volts phase-to-ground in order to supply the power for the reference circuit.

20-25. *Current transformers.* The boost current transformers are used to supply the voltage required by the second-stage amplifier during short-circuit conditions. The secondary voltage of a current transformer will be approximately 20 volts at 200 percent short-circuit current. If the current transformers are not connected, the regulator will not have sufficient power for the magnetic amplifier power circuit, and therefore the system will cycle as if there were no reference current. If the current transformers are connected in reverse, there will be a decreasing system voltage as load is applied to the generator.

20-26. *Starting relay.* The starting relay is used to short out the regulator, complete the exciter field circuit, and allow the generator to build up under self-excitation. The opening voltage of the relay is approximately 195 volts phase-to-phase. Should the relay have an open coil or welded contacts, the power system will go to overvoltage, 300 volts at 400 Hz. On the other hand, high-resistance contacts will keep the generator from building up. With the field flashing circuit there should be no difficulty due to high-resistance contacts.

20-27. *Bias circuit.* The bias circuit is used to bias the second-stage magnetic amplifier to minimum, opposing the first-stage output power. The output of the bias circuit is approximately 32 milliamperes. Should this signal be lost, the regulator output will tend to be high, forcing the system voltage high.

20-28. **Amplifier Stages.** The first stage magnetic amplifier is a self-saturating, single-phase, full-wave, magnetic amplifier. Of the two stages of magnetic amplification, the first stage is the most important, since it determines what happens to the system voltage during normal operating conditions. The second stage is used only for power amplification, whereas the first stage not only amplifies but also receives all of the converging system signals which cause the voltage regulator to maintain a constant generator output voltage. The most common failure in the first stage is probably in one of the rectifiers. Complete failure of rectification can cause the regulator output to go to zero. If one saturating rectifier fails, the regulator will indicate instability. Other failures, such as an open winding or shorted turns, are very unlikely.

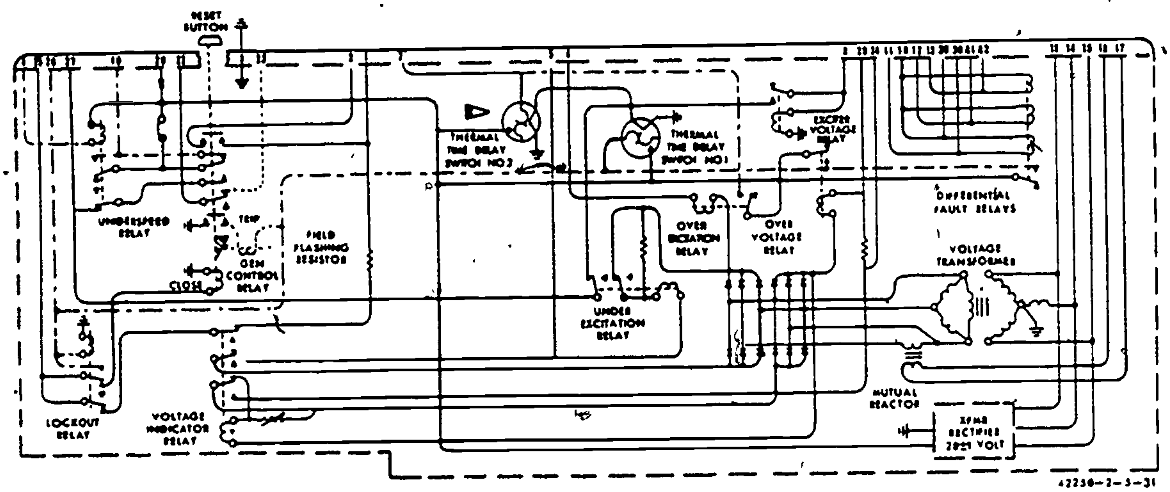

Figure 62. Typical generator control panel.

20-29. The second-stage magnetic amplifier is a three-phase, self-saturating, full-wave type. This is the power stage, and it is controlled by the first stage in such a manner that the power supplied to the generator exciter is regulated to maintain rated system voltage.

20-30. The commutating rectifier consists of a half-wave, 60-volt cell connected across the output of the second-stage magnetic amplifier in parallel with the shunt field of the exciter. This rectifier, connected across the inductive load, improves the response time of the regulator. When this rectifier is open, the system voltage will collapse, since there would then be a dead short across the shunt field.

Paragraph 20-31 deleted.

20-32 **Generator Control Panel.** The typical control panel selected for this discussion contains the necessary relays and sensing units to perform such functions as generator field flashing, generator exciter control, anticycling, and overvoltage protection. Overexcitation and underexcitation protection, underspeed protection, exciter protection, and fault protection.

20-33. A typical generator control panel is shown in figure 62. We shall discuss each of the components in the control panel and see exactly how and when each unit operates. Later in this volume you will see how the generator control panel in an operating system functions in conjunction with the other units of a generator system.

20-34. *Generator control relay.* The generator control relay (see fig. 62) is used to open or close the exciter field of the generator. It is an electrically operated, mechanically latched relay. The "close" coil of the GCR is connected to the "close" side of the generator switch (not shown). When the generator switch is moved to the CLOSE position, the "close" coil is energized, pulling the contacts into the closed position, where they are held in place by the mechanical latch. At the same time, the exciter field of the generator is momentarily flashed.

20-35. The trip coil of the GCR is energized by moving the generator switch to the TRIP position, or by the operation of certain protective devices within the control panel. When the trip coil is energized, it releases the mechanical latch, and spring tension moves all the contacts into the OPEN position.

20-36. *Lockout relay.* The lockout relay (see fig. 62) is used to prevent generator cycling during a fault condition. The lockout relay coil is connected across the trip coil of the GCR so that both coils are energized simultaneously. Therefore, any control action—manual or automatic—that trips the generator out through the GCR will cause the lockout relay to energize. When energized, the lockout relay interrupts the field flashing circuit and opens the circuit to the "close" coil of the GCR. Since the "close" circuit is complete through the deenergized contacts of the lockout, you can see that if the generator switch is moved to the CLOSE position while the lockout relay is energized, the only result will be to keep the lockout relay energized as long as the trip fault exists.

20-37. *Underspeed relay.* The underspeed relay (fig. 62) is provided to disconnect the generator from the aircraft distribution system in case the drive goes into an underspeed condition. The ground for the underspeed relay is completed when the underspeed pressure switch on the generator drive closes.

20-38. *Differential fault relays.* The differential fault relays (fig. 62) provide fault protection for the generator and the generator feeder wires. A fault within a generator or in any of the generator feeder wires will result in a greater current flowing in the neutral lead of the faulted phase than flows to the power distribution system through the feeder wires. The sensing of this differential fault is done through ring-type current transformers for each phase, one on the generator neutral lead and one on each of the feeders supplying power to the power distribution system. The neutral and distribution feeder transformers for each phase are connected in parallel across the differential fault relay coils in the generator control panel. During normal operation, the current through the neutral and distribution feeders will be the same; the voltages induced in the two current transformers of each phase will be equal and opposite, and no current will flow in the relay coil. When a fault occurs, the voltages induced in the two transformers differ by the amount of fault current which produces current flow in the relay coil. A fault causing a 30-ampere differential current will instantly close the differential fault relay contact to trip out the GCR of the faulted generator. This effectively removes the generator from the system.

20-39. A balanced three-phase fault on the interconnecting feeder wires when two or more generators are operating in parallel will produce excessive exciter armature voltage and system under-voltage on all the generators. Excessive exciter voltage is sensed by the exciter voltage relay (fig. 62) and undervoltage is sensed by the excitation relay. Both relays energize the heating elements of the thermal time-delay switches (also shown in fig. 62). Thermal time-delay switch Nr. 2 will close in from 2 to 4 seconds and isolate that generator from the rest of the system. If the trouble continues, thermal time-delay switch Nr. 1 will close in from 5 to 10 seconds and energize the trip coil of the GCR for that generator.

20-40. *Overexcitation-underexcitation protection circuit.* Protection against excessive reactive current flow in the generators and reactive unbalance in the distribution system is provided by the overexcitation-underexcitation (OE-UE) circuit. The OVEREXCITATION relay and the UNDEREXCITATION relay in each generator control relay automatically control isolating or tripping the generators in parallel when such malfunctions occur. The overexcitation relay functions to isolate the defective generator from the remaining generators. The underexcitation relay controls tripping the GCR through the thermal time-delay switches. Note that both the underexcitation relay and the overexcitation relay are energized during normal operation and complete their respective circuits only when de-energized.

20-41. The wye-delta transformer and full-wave rectifier shown in figure 62 are used to supply operating power and the generator reference voltage to the OE-UE relays. The voltage to the relays will be increased or decreased, depending on the amount and direction of the unbalanced reactive current of one generator relative to that of the other generators. This is achieved by connecting a current transformer so that its output is applied to the mutual reactor, also shown in figure 62. The mutual reactor affects one phase of the voltage being applied to the full-wave rectifier. The current transformers and mutual reactors of all the generators are connected into a loop circuit known as the OE-UE loop.

20-42. The OE-UE loop functions only when the generators are paralleled together. As long as the reactive load is equally divided, the voltages in the OE-UE loop are balanced, and the overexcitation relay will function only if an overvoltage condition occurs. Overexcitation, which causes reactive unbalance due to excessive reactive current in that generator, will produce a current flow in the mutual reactors. The direction of flow in the OE-UE loop through the mutual reactors produces a voltage that boosts the voltage sensed from the overexcited generator. Consequently, the overexcited generator will be switched into isolated operation by the overexcitation relay.

20-43. Underexcitation, which causes reverse reactive current flow in a generator, will produce mutual reactor current that opposes the voltage sensed from the underexcited generator, so that the underexcitation relay drops out. The underexcitation relay controls the thermal time-delay switches. Thermal time-delay switch Nr. 2 places the generator in isolated operation in 2 to 4 seconds, while thermal time-delay switch Nr. 1 will trip the GCR in 5 to 10 seconds.

21. AC Generator System Operation and Troubleshooting

21-1. In this section we will discuss operation, power distribution, external power systems, and troubleshooting of an ac generator system. Our detailed discussion of the many ac generator system components will now be put to work. Foldout 2 is a complete ac generator system and is used for our discussion of system operation and troubleshooting.

21-2. Keep in mind that you must be able to understand complete generator system operation.

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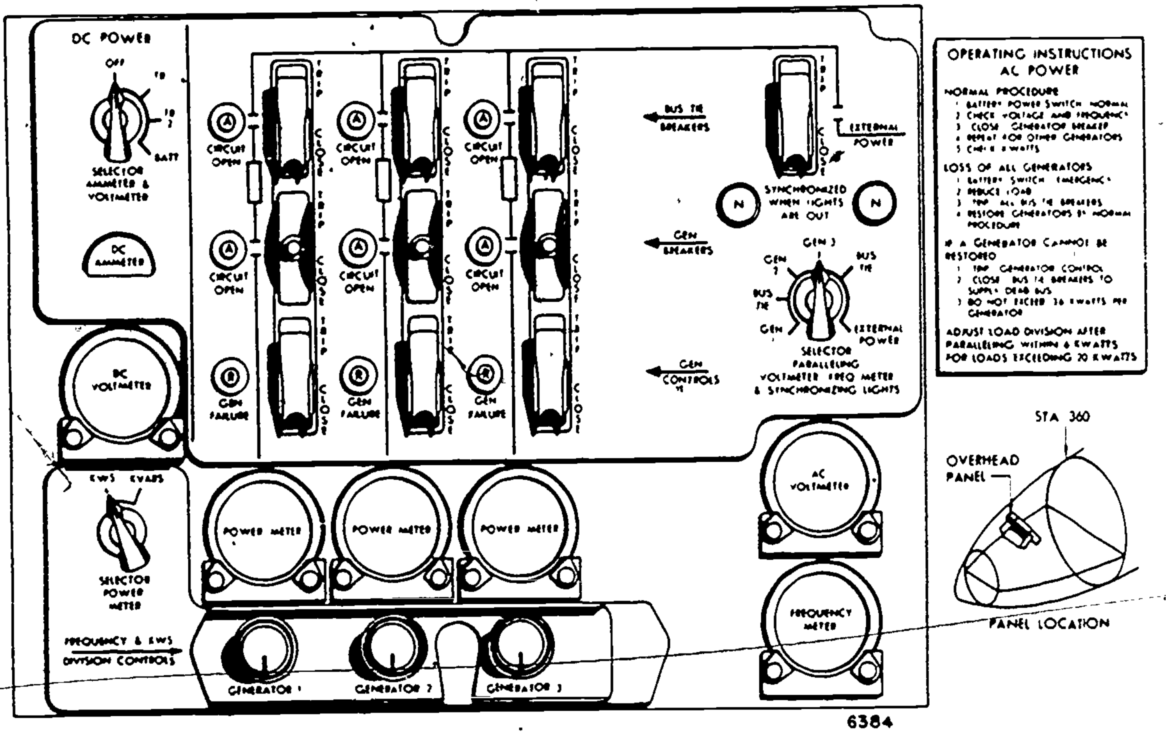

Figure 63. Multi-engine control panel.

Why? It's your job to maintain and troubleshoot ac generator control systems. We will start our discussion with normal system operation.

21-3. **AC Generator System Operation.** The generator system we are going to discuss has three 40 kva generators. The generator provides a three-phase, 115/200-volt, ac output at an essentially constant frequency of 400 Hz.

21-4. *Description.* A frequency and load controller unit for each constant speed drive accomplishes frequency control, and real load division for parallel operation of the generators. The frequency and load controller responds to frequency deviation from 400 Hz or real load unbalance between paralleled generators and controls the speed governor setting of the generator drive. The electrical control of the speed governor is accomplished through a control motor on the drive. Generator voltage control and reactive load division are accomplished by a static type (magnetic amplifier) voltage regulator unit for each generator. The ac generators provide their own dc power for field excitation through a self contained dc generator exciter. The voltage regulators control the field current of the exciters to vary the generator field strength and subsequently maintain the generator voltage output at 200 volts line to line. Several current transformers are contained in a transformer assembly and connected to sense generator line current. These transformers provide load sensing, both real and reactive, for the power meter and load equalizing controls and provide for voltage regulator power boost.

21-5. The control switches, selectors and indicators for the main ac power supply system are grouped on the electrical control panel (fig. 63), which is a section of the overhead panel. The generator control switches control closing the generator fields and associated circuits to return a tripped generator to service, and provide the manual control to trip a generator off. The generator breaker and bus tie breaker switches are the manual controls for opening and closing their respective power breakers. The generator breakers connect the generators to the load buses. The bus tie breakers connect the load buses to the synchronizing bus tie. Indicator lights adjacent to the generator control and breaker switches show the control condition for each generator system. The generator failure lights indicate when a generator is tripped off, which might be done manually, or automatically through a protective control. The breaker CIRCUIT OPEN indicator lights are on when their respective breakers are open. The voltmeter and frequency meter are connected to show the voltage and frequency of the source selected by the paralleling selector. The paralleling selector also connects the synchronizing lights and automatic paralleling control unit into the circuit of the generator selected for paralleling. The power meters,

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one for each generator, provide the indication of real load (kilowatts) or reactive load (kilovolt-amperes-reactive) on each generator. Real or reactive load indication is selected by turning the power meter selector to the KWS or KVARS position. The three frequency and kws division controls immediately below the power meters are used for real load division control with the generators paralleled and as a frequency control to synchronize the generators for paralleling.

21-6. The majority of the control relays and automatic protective controls for each generator system are contained in the generator control panel. In each generator control panel are the necessary relays and sensing units to provide the necessary control functions of the system. The control panels also contain a transformer-rectifier unit and voltage indicating relay. The T-R unit normally supplies the 28-volt dc power for panel functions while the generator is operating. Power is also supplied to the panel from the airplane switched dc bus. The voltage indicating relay energizes only when there is three-phase power to the panel to prevent residual voltage from an unexcited generator from holding in control relays.

21-7. *Operation.* (See foldout 2.) The generator control relay must be closed to establish the exciter field circuit and the generator breaker control circuit before a generator can develop its required output voltage and be connected to its load bus. The generator control switch on the electrical control panel controls closing the generator control relay. With power on the airplane (battery bus energized) and the engine fire switch to normal, operating the generator switch momentarily to the CLOSE position will cause the generator control relay to mechanically latch closed. Closing the switch will also transfer power to the exciter field through the flashing resistor. With the generator control relay closed, the relay contacts complete the exciter field circuit, connect control power to the generator breaker switch if the drive is up to speed, turn off the generator failure light and arm the relay trip coil circuit. The field flashing resistor circuit is opened by the voltage indicator relay as soon as generator output powers the control panel. With the generator control circuit established by closing the control relay, the voltage and frequency of the generator can be read on the meters by placing the paralleling selector to the correct generator position. However, the generator is not supplying its load bus until the generator breaker is closed.

21-8. The generator breaker switch on the electrical control panel is the manual control for closing and tripping (opening) the generator breaker. During normal system operation, the generators will be paralleled by closing the generator breakers; the bus tie breakers normally are left closed, and are opened only for isolated generator operation or for manual control of paralleling. With power on the synchronizing bus tie, the generator breakers can only be closed through operation of the automatic paralleling unit.

21-9. The control transfer between manual and auto parallel control of the generator breaker is accomplished by the auto parallel control relay which is energized by ac power from the bus tie. With the paralleling selector set to the correct generator position, operating the generator breaker switch to the CLOSE position will connect the generator output to the auto parallel unit. This permits frequency comparison with the generator already on the synchronizing bus, so that the auto parallel unit can switch power to close the generator breaker when the frequencies match closely enough in both phase and rate. If there is no generator on the synchronizing bus at the time the generator breaker switch is operated to CLOSE, the switch directly controls closing the generator breaker provided the external power breaker is open. A contact of each generator breaker switch is connected to automatically trip open the external power breaker when the switch is operated to the CLOSE position.

21-10. During manual paralleling of the generators, the bus tie breakers are opened and generator breakers are closed to allow the generators to supply individual generator buses until paralleled. The generator to be paralleled must match synchronizing bus voltage and frequency within 5 volts and 2 Hz before the bus tie breaker is closed. Rotating the paralleling selector switch to the applicable position will provide voltmeter and frequency meter readings for the incoming generator and cause the synchronizing lights to operate. The lights will light up and darken as many times per second as there are cycles per second difference in frequency between synchronizing bus and generator bus power. The bus tie breaker switch is positioned to CLOSED at the particular instant when the voltage is within limits and the synchronizing lights go out. During manual paralleling of the generators, the BUS TIE BREAKER switch must not be placed in the CLOSE position unless the following conditions exist: the paralleling selector switch is positioned to the incoming generator and the synchronizing lights are out.

21-11. Failure to observe these precautions may result in damage to the generator drive due

to loads imposed by opposing voltages. If frequency adjustment is necessary before the generator can be paralleled, you may use the frequency and kw division controls on the electrical control panel to make the necessary adjustments.

21-12. Normal operating procedures at engine shutdown will cause the generator breaker to automatically disconnect the load buses from the generator. An underspeed switch on the generator drive is set to close and cause the generator breaker to trip open before the generator frequency is less than 350 Hz. The underspeed switch controls energizing the underspeed relay in the generator control panel. (See foldout 2.) When underspeed occurs, the underspeed switch closes to energize the relay which switches power to trip open the generator breaker and remove power from the breaker control switch.

21-13. The bus tie breakers and generator control relays will normally remain closed when the system is shut down. Therefore, the next time the engines are started and run, the generator breakers are all that require closing to supply ac power to the load buses and to parallel the generators. The underspeed switch also functions to prevent the generator from being closed before the generator drive speed is adequate to drive the generator at synchronous speed. The underspeed switch should operate to drop out the underspeed relay, on increasing drive speed, before the frequency exceeds 370 Hz.

21-14. Generator control anticycling is provided through the lockout relay in the generator control panel (foldout 2). The lockout relay coil is connected across the trip coil of the generator control relay so that both coils are energized at the same time. Therefore, any control action, manual or automatic, that trips out the generator through the control relay will cause the lockout relay to pull in and hold open the control relay close coil circuit as well as the field flashing circuit. If the generator control switch is being held to the CLOSE position when the trip signal occurs, the lockout relay will be held in by power through the control switch, preventing reclosing of the generator control relay until the control switch is returned to off.

21-15. *Distribution.* An aircraft distribution system is made up of many wires and power boxes throughout the aircraft. It provides a means of distributing the generator output to all the various loads in the aircraft. The switches and meters used to control and monitor the generator and distribution system are shown in figure 63.

21-16. The portion of the system between the output terminals of the generator and the main bus is generally referred to as the generator bus. When the generator breaker is closed, it connects the output of the generator to the main bus. The main bus is the portion of the distribution system to which the loads are connected. Feeder wires from the main busses go out to various load boxes located throughout the aircraft. The central tie bus is the interconnecting wire between the various main busses, and no loads are connected to this bus. When external power is connected to the aircraft, it powers the central tie bus. Thus, it is necessary to close all the bus tie breakers and connect the main bus to the central tie bus. All the loads in the aircraft may be powered from the central tie bus. During parallel generator operation, all the bus tie breakers and all the generator breakers are closed, and the total electric load on the distribution system is shared by the generators.

21-17. **External Power System.** The primary purpose of any external power system is to allow ground maintenance personnel to perform operational checks on the electrical and electronic equipment when the aircraft generators are not powering the aircraft busses. The external power system also provides a means of connecting a load bank to the main ac power system. The purpose of connecting a load bank is to allow electrical maintenance personnel to perform an operational check of the main power system. The multiengine external power system shown in figure 64 is typical for many aircraft.

21-18. One thing you must keep in mind (and this applies to most external power systems) is that at no time should the aircraft generators and the external power unit generator be paralleled. Due to this restriction, the control system may seem to be very elaborate.

21-19. *Description.* The external power control system consists of the following components. main external power receptacle, phase sequence relay, power control relay, circuit breaker relay, lockout relay, and the power disarm relay, as shown in fig. 64. The position indicator, EXT POWER switch, and the BUS TIE ISOLATE switch are always located on the ac control panel in the cockpit area.

21-20. The main external power receptacle provides a means of connecting external three-phase ac power to the aircraft power system. The receptacle is also used to connect a load bank to the central tie bus. Three pins, A, B, and C, connect the ac power to the aircraft system. Pin E provides the dc control power required for closing the external power control relay. Pin F is used for load bank operation only and provides a ground for the external power disarm relay.

21-21. The phase sequence relay is used to prevent external ac power from being connected

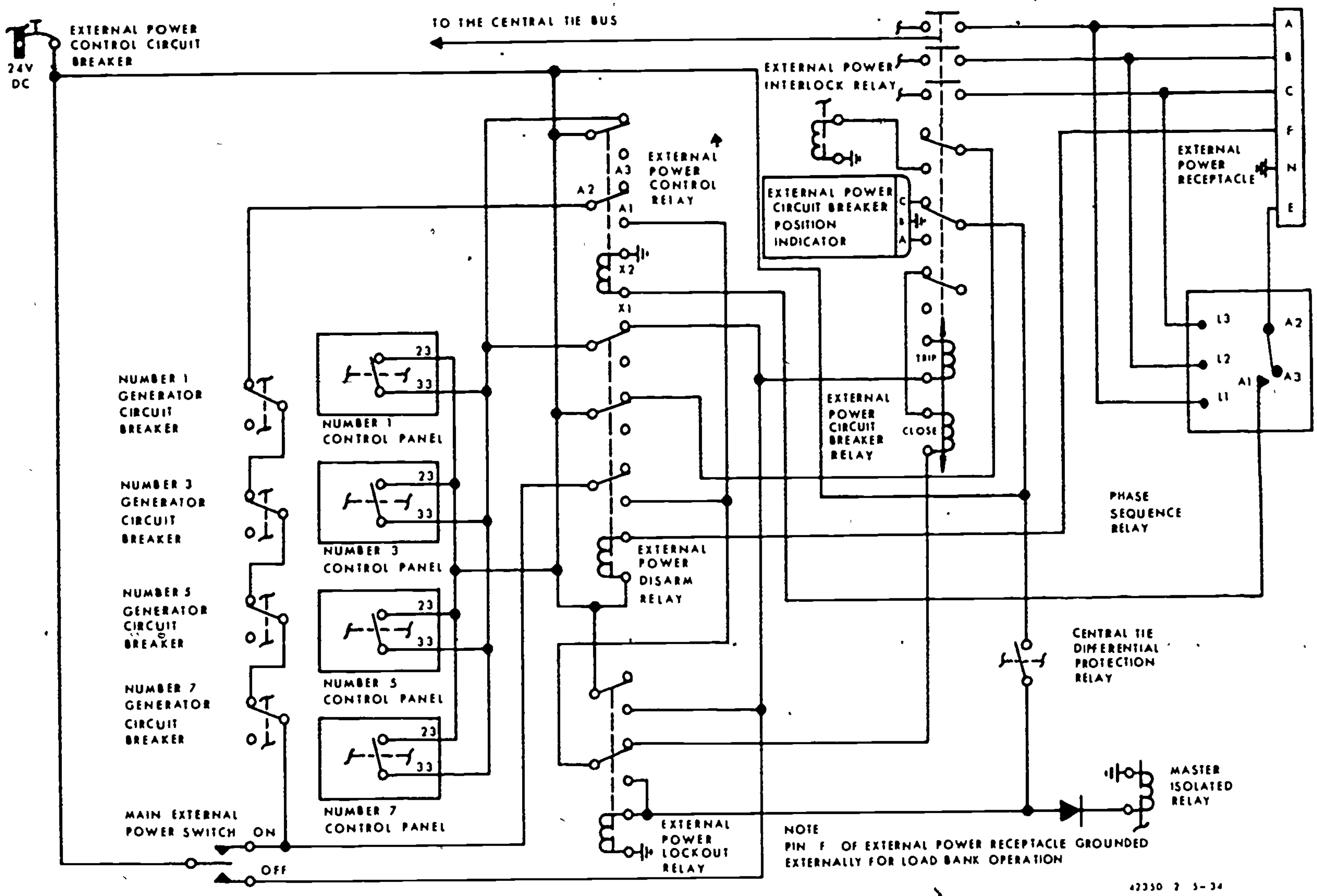

Figure 64. External power control system.

to the aircraft bus when the phase sequence is incorrect (other than A-B-C or 1-2-3). This relay will be energized if the phase sequence is correct.

21-22. The external power control relay is powered by 28 volts dc from the external power cart through pin E and the phase sequence relay.

21-23. The external power circuit breaker relay is a latch-type relay of the same type used for the generator breaker and bus tie breakers. This circuit breaker is used to connect and disconnect external power to the central bus. The external power breaker uses three sets of its five auxiliary contacts; one is used to control the "close" and "trip" coil circuit to ground, a second set is used to control the external power interlock relay to prevent a generator breaker from being closed before external power is tripped, and a third set is used to control the main external power circuit breaker relay position indicator.

21-24. The main external power lockout relay is energized any time a central tie bus fault occurs. The relay is powered from the aircraft dc power system. The lockout relay contacts control the external power breaker "close" and "trip" coil circuits.

21-25. The only purpose of the disarm relay is to provide a means of connecting an external load bank to the central tie bus when the aircraft generators are operating. Under normal conditions, we don't want the external power breaker to close when the aircraft generators are on the bus, but in this case, we do. Pin F of the external power receptacle provides a ground return for the coil of the disarm relay when the load bank is connected to the receptacle.

21-26. A typical circuit breaker relay position indicator has white bars running vertically and horizontally. The word "OFF" is also printed on the indicator. When the bar is lined up with the reference on the ac control panel, the circuit breaker is closed; and when the bar is at a right angle to the reference line, the breaker is open. When the word "OFF" is showing, the indicator is not powered.

21-27. *Operation.* When external power is connected to the external power receptacle, there are 118/205 volts ac applied to the phase sequence relay. If the phase sequence is correct (A-B-C), contacts between A1 and A2 will close (see fig. 64). With the phase sequence relay closed, 28 volts dc from pin E will be applied through contacts A1 and A2 to the external power control relay, closing it. When the main external power switch is turned to ON, 28 volts dc from the external power control circuit breaker is applied to the "close" coil of the external power breaker, the main external power switch, through the auxiliary contacts of the four generator breakers, a set of contacts of the external power control relay, through the contacts of the deenergized external power lockout relay, and to the "close" coil of the external power breaker, closing it. When the external power breaker closes, a set of its contacts will energize the external power interlock relay. The interlock relay prevents closing a generator breaker when external power is connected to the central bus. The interlock relay contacts are in series with the generator breaker "close" coil. Should a generator be operated and the generator switch turned to ON, the G relay in the generator control panel will be energized and will close the contacts between terminals 23 and 33. This will cause a 28-volt dc signal to be impressed at terminal 33 through the external power disarm relay, to the external power breaker trip coil, disconnecting the external power from the central tie bus.

21-28. When the main EXT POWER switch is turned to OFF, 28 volts dc is applied directly to the trip coil of the external power breaker, disconnecting external power from the central bus. External power is protected by a differential protection system. This system protects the three-phase ac power system from line-to-ground, line-to-line, and three-phase faults.

21-29. A typical ac power distribution system is so designed that it is possible to operate any load from external power, from the engine generators, or from all of the generators paralleled together. The following are possible conditions:

a. External power to the complete aircraft. This is achieved by closing the external power circuit breaker and the bus tie circuit breaker.

b. External power to any load. To do this, close the external power circuit breaker and the bus tie circuit breaker to the load bus on which you desire power.

c. Each generator supplying its respective load. Close the generator circuit breakers, and leave the bus tie circuit open.

d. One generator supplying power for the entire aircraft. Close the generator circuit breaker for the operating engine, and close all of the bus tie circuit breakers.

e. All generators operating in parallel. Close all of the bus tie circuit breakers. Then, move the paralleling selector switch to the generator that you desire on the synchronizing bus. This closes the respective generator circuit breaker. Follow this procedure through the three generators. Then, all generators are paralleled automatically through the paralleling unit.

f. Various combinations of two generators paralleled and one running in isolation.

21-30. *Load bank operation*. Provisions have been made in this external power system to utilize the main external power receptacle for connecting a load bank to the aircraft bus.

21-31. When type A1 load bank is connected to the external power receptacle, the external power disarm relay circuit is energized by 28 volts dc from the external power control circuit breaker. This connection is made through the relay coil (disarm relay) to pin F of the external power receptacle, which is grounded at the load bank. This provides a circuit from the main EXT POWER switch on the ac control panel, through a set of contacts on the now energized external power disarm relay, and on through the external power lockout relay to the "close" coil of the external power breaker. When the external power disarm relay is energized, the power circuit to the interlock relay opens. With the interlock relay deenergized, its contacts, in series with the generator breaker, close and allow the generator breaker to close and connect the load bank to any one or all of the generators through these generator breakers. External power can be isolated to the central tie bus by pushing the BUS TIE ISOLATE switch. Pushing the BUS TIE ISOLATE switch trips all bus tie breakers.

21-32. **Generator System Troubleshooting.** Troubleshooting is a test of ingenuity as well as of knowledge. For this reason troubleshooting procedures cannot be considered as an ironclad ruler, although they are written as such. Experience will increase your knowledge of various electrical systems and reveal new checks and more efficient methods of troubleshooting. As you gain experience, you will be able to devise new methods as well as short cuts to eliminate lengthy checks for similar trouble.

21-33. Although you have a firm background in electrical fundamentals, this is still not enough to enable you to do your job with ease. In addition to the fundamental information you possess, you must have a thorough understanding of troubleshooting procedures. Realistic troubleshooting is not a "hit-or-miss," "remove-and-replace," "trial-and-error" process; it is an orderly sequence of mental and physical actions—ending with the identification and elimination of a system malfunction. A combination of maintenance skills, intimate knowledge of the operation of the system, and the use of logical steps in the problem-solving process are essential to systematic troubleshooting.

21-34. **Steps in Becoming a Master Electrician.** One outstanding difference between being just a good worker and being a master repairman is the ability to troubleshoot. When everything is functioning normally, the good worker can perform the routine day-to-day maintenance, servicing, inspecting, and operational checks. The good worker can also make routine adjustments and replacement of units, since they follow the well-beaten path laid down by technical procedures. The "master" repairman or electrician, however, is the man who is really in demand, because he is the one who can find the *causes* of troubles that have baffled other workers.

21-35. Since you, no doubt, would like to become a master electrician or technician, here's a tip that may be helpful: adopt some good method of troubleshooting now, and use it constantly until it becomes automatic. The more automatic the method becomes, the more effective your use of it will be.

21-36. Although there are numerous troubleshooting procedures that you might adopt, let us consider a procedure that experienced troubleshooters have found very successful. We said earlier that you must use logical steps to identify and remedy system malfunctions. Let's list these steps, then discuss each of them in detail.

(1) Define the problem.
(2) Investigate the problem.
(3) Evaluate the findings.
(4) Determine the exact cause.
(5) Repair or remedy.

21-37. *Define the problem*. Your careful inspections and operational checks are the key to your becoming aware of the trouble. Perform an operational check that is as complete as is practical under the circumstances. Of course, if your operational check is causing obvious damage, it has gone beyond the point of being practical. While the operational check is in progress, notice all indications given by the operated unit or system, and by related warning lights and meters. Place the control switch in all operating positions, if practical, and set clearly in mind the symptoms in each position. If you have done all this, you are ready for step two—investigating the problem.

21-38. *Investigate the problem*. Of course, you have a good idea of the system operation, but in step two of the troubleshooting method you refresh and supplement this knowledge. Consult the technical manuals. Read about the affected system in the applicable publication for the aircraft and study the circuit wiring diagram. The time that you require for this study is small compared with that required for hit-and-miss replacement of units. After you have refreshed your knowledge of the affected system, you are ready for step three of the troubleshooting method—evaluating the findings.

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21-39. *Evaluate the findings.* In the third step of troubleshooting, you should list the possible troubles. By writing them down, you are less likely to forget one or more of them during later steps of troubleshooting. Then, too, listing the troubles relieves you of the necessity of remembering each of them. Since your mind is less cluttered by details, you can think more clearly. In addition, there is another advantage: making such a list is an eye-opening device. Many times a possibility will seem logical to you, but—as you write it down—the balloon of logic that apparently supported it may suddenly burst, and you can scratch it off your list. So by all means, make a written list of the possible troubles.

21-40. While making this list, use a wiring diagram, trace the circuit through, and ask yourself, "What defect of this wire or unit could give any one of the symptoms I have observed?" If you get an answer other than NONE, write it down. Make a similar list for each symptom you find. Don't list double troubles which happen only rarely, but make certain that your list contains all possible single troubles. Compare the causes you have listed to determine which are the most probable, then list them in that order. When your list is completed, you are ready for step four of the troubleshooting method—selecting the exact cause from the list you have made.

21-41. *Determine the exact cause.* In the fourth step of troubleshooting, you should check possibilities and eliminate those not actually responsible for the trouble. To check some possibilities, you may be required to remove inspection panels or other aircraft components. To check others, you may need to remove a junction box cover. Still other possibilities may be eliminated by a visual check, such as looking at a circuit breaker to see whether it is closed. Which should you check first? The answer is obvious. Check the easiest things first. In other words, check the circuit breaker first. That's a good check to make at the beginning of any troubleshooting situation. By checking the easiest things first, you may find the cause of the trouble before you perform other time-consuming checks. If so, you have saved time, work, and a great deal of wear and tear on the aircraft.

21-42. Applying the same line of reasoning to each possible trouble, you come up with another useful principle. Use the easiest method that is both safe and effective while you are checking any possibility. Never disassemble a unit or disconnect a lead unless absolutely necessary. If there is an easier way to check a possible problem, use it. Your imagination and knowledge of the system can pay big dividends. However, don't allow your imagination to run wild. Before you attempt the easiest way, make certain that it is safe and that it will actually check the possibility. These two principles are contained in a simple general rule: "Check the easiest thing first by using the easiest method that is both safe and effective."

21-43. If you apply this rule, you can quickly and easily eliminate possibilities until you discover the cause of the trouble. But even then, do you know that you are right? Not necessarily! You probably are, but you should prove your conclusion.

21-44. *Repair or remedy.* Before you make a costly replacement, prove that your conclusion is right. For example, let's say that you have eliminated every possible cause of trouble from your list except "shorted-out field windings of such-and-such a motor." In this event, you probably have decided that shorted-out field windings are the actual cause of the trouble. But you could have left some possible causes of trouble off your list. So, before you remove the motor for a bench check, disconnect the connector plug and use an appropriate meter to test for such a short. If you prove yourself wrong, you haven't wasted time, work, or money on a needless replacement. If you prove your conclusion to be right, you need to replace the shorted-out motor.

21-45. Without troubles, there would be practically nothing for you to do as an electrician except to perform routine inspections and similar work. Identifying and locating troubles is the exciting and thought-provoking part of your work. In certain circuits a trouble often repeats itself in the same precise location or in the same piece of equipment. You ordinarily become so familiar with this type of trouble that you can easily identify and locate it every time it happens. On the other hand, some equipment frequently remains trouble-free over a period of time. Nevertheless, when troubles do develop in such equipment, you must be able to find them. Typical of many aircraft circuits are those that have circuits acting independently within themselves. All of these individual circuits must operate properly or the parent circuit will malfunction in one way or another. For example, a parent circuit might control a sequence of operations performed by a mechanism, and if one of the independent circuits should malfunction, a corresponding operation in the sequence would be affected.

21-46. We have now covered the steps which should be followed in determining system malfunctions. Next, by discussing how you can apply these steps to some specific problem, we will show you how they can help you.

21-47. **Typical Problem.** For this problem, assume that you are told that the generator breaker for this system fails to open automatically when the generator is shut down. When you operate the generator to perform the operational check, you discover that the generator breaker can be tripped manually by means of the GENERATOR BREAKER switch, but that the generator breaker does not trip automatically when the generator is shut down. The trouble may now be defined as follows: "The generator breaker may be tripped manually but not automatically." This definition also helps you to list the possible causes of troubles. Since the breaker may be tripped manually, you know that most of the circuit to the trip coil of the generator breaker must be intact. Here, then, is a list of all the remaining possibilities:

- No power to the control panel.
- No power output from the control panel.
- Defective control panel.
- Defective underspeed switch.

21-48. By examining foldout 2, you note that dc power is applied to the control panel through pins 20 and 22. Checking for dc at these points, you find that it is available. The next check is to find out whether or not power is available at pin 19 of the control panel, which is the output circuit to the trip coil of the generator breaker. Let's assume that you checked at this point and found zero volts. This tells you that you have a defective generator control panel. You could check to verify that the circuit breaker, shown inside the control panel, was set, since the dc power supply to the control panel flows through this circuit breaker. Another quick check you might make is to replace the suspected control panel with one that is known to be good, then perform another operational check. If the trouble no longer exists, you would know that the control panel is defective. Of course, you have no way of knowing exactly what is wrong with the defective control panel until you test it with the appropriate test equipment.

21-49. This concludes the discussion of the step-by-step procedures you would normally make when troubleshooting specific problems. Now we will turn our attention to analyzing some of the more common troubles you will encounter in ac systems.

21-50. **Trouble Analysis.** As you gain experience, you will find that in most cases certain troubles are caused only by certain components in the electrical system and that you will be wasting your time if you check items that have nothing to do with the trouble.

21-51. *Frequency problems.* In almost all cases, frequency problems consist of either constant frequencies which are higher or lower than normal system frequency. Since only certain units are used to control the generator frequency, troubles of this nature usually present no great difficulty. For example, one of the most common causes of troubles are higher or lower than normal frequency which may be caused by a defective frequency-and-load control unit or by the drive governor system. To determine which unit is malfunctioning, disconnect the circuit from the frequency-and-load control unit and operate the engine at idle rpm. If the generator frequency is the same as that established by the drive governor (up to 50 percent load), the governor is functioning normally, and the frequency-and-load control unit is defective. An open circuit in the magnetically trimmed governor circuit will also cause the generator frequency to drop to basic speed. You can also check a drive governor system by rotating the "frequency and kws division" control on the control unit. If the frequency cannot be varied and the circuitry to the governor is correct, the governor is defective. Before you replace a drive unit, however, it is best to test the frequency-and-load control unit on the T-35 or T-170 tester.

21-52. You may also encounter a frequency problem in which the frequency of an isolated generator decreases when a load is added. As you have learned, the load-sensing circuits are shorted out by the bus tie breakers and generator breakers when they are in the OPEN position. This prevents an inoperative or isolated generator from affecting the remaining system. If you encounter this type of problem, then, you can suspect that a trouble exists somewhere in the circuits that shorts out the load-sensing network.

21-53. A generator frequency that is either high or low, and is uncontrollable, is the result of a malfunction in the frequency discriminator circuit in the frequency-and-load control unit. What about the frequency problems in pneumatic-drive generator systems? In addition to the troubles in the frequency-and-load circuits, similar to those we have just discussed, there are several troubles that are peculiar only to these drives. Since the pneumatic drives operate on air pressure, low frequency output may be caused by insufficient air pressure. Another cause of abnormal frequency output may be the improper adjustment of the valve linkage. You may find it necessary to ask for assistance from other work centers to check for the cause of this particular problem.

21-54. *Voltage problems.* Another common trouble you will no doubt encounter is one in

which the generator or bus voltage is higher or lower than normal. Voltage troubles are usually caused by the voltage regulator, the generator, or—in some cases—the generator drive. Low output from the generator may be caused by a generator drive that remains in the underdrive condition or by excessively worn brushes. Some of the other possible causes of low output voltage are high resistance in either the exciter input or output circuit to the generator. An open in the exciter output circuit of a brushless generator can cause low generator output voltage. A defective voltage adjusting potentiometer can also cause low voltage output. You may detect this by rotating the potentiometer while observing the exciter voltage. If there is no variation, the voltage regulator should be replaced.

21-55. If the bus voltage is low when two or more generators are operating in parallel, it is an indication of an open reactive load equalizing loop circuit. When this condition exists, all of the bus tie breakers in the system will trip open when a medium or heavy load is applied to the bus. The loss of the first-stage amplifier in a mag-amp voltage regulator causes low output voltage from the generator. If the reference circuit of a mag-amp voltage regulator is lost, the output voltage of the generator will not only be below normal but will cycle between 100 and 200 volts.

21-56. High voltage output is most generally caused by a defective or maladjusted voltage regulator. For example, loss of either the sensing or bias circuit of a mag-amp voltage regulator will cause the generator output voltage to become excessive. Another cause for excessive generator output is higher-than-normal output from the exciter-generator. You can usually detect this by measuring the exciter output while rotating the voltage adjusting potentiometer on the voltage regulator.

21-57. The loss of one phase of the input to a carbon-pile voltage regulator will cause an excessively high generator output. In some cases, you may find that the generator itself is the cause of voltage problems. If there is no voltage output from the generator, you may find oil, dirt, or grease on the commutator on the exciter generator. This causes a high resistance on the commutator, and the generator output will be zero, or residual. Remember, there should be a dull copper-colored film on the commutator. If the film is removed, the brushes will wear down very rapidly and cause low output voltage. This is an important point for you to remember when it is necessary to operate a generator on a test stand for long periods of time. You must keep the generator excited, and under load to prevent destroying the film.

21-58. *Load-division problems.* Load-division problems are probably the most difficult and thought-provoking problems that you will encounter. These are the types of problems that really test your knowledge of electrical systems and your ingenuity in troubleshooting.

21-59. You can discover load-division problems in many ways. A generator in parallel operation may not carry its share of the kw or kvar load, or it may try to "hog" the load and carry more than its share. In some cases, you may notice a marked tendency for generators operating in parallel to swap the load back and forth between them. In cases of extreme load underbalance, one or more bus tie breakers may trip open. For example, an overexcited generator in parallel will tend to carry more than its share of the reactive load, and the overexcitation protective device will automatically open the bus tie breaker for that generator.

21-60. Suppose you have discovered a load-division problem. After testing the frequency-and-load control units or the voltage regulators, you find that they are functioning normally. Obviously, the trouble must be somewhere in the sensing circuits for these components. You recall from previous discussions that the load-division circuits receive their input signals from current transformers. The current transformers are the source of many malfunctions in the load-division circuits. Their characteristics are very easily changed. This is caused either by installing them incorrectly, or by failing to short them out when they are being operated. If maintenance has recently been performed on the affected system, it is worthwhile to check the current transformers of the system for proper connection. Another check you should make is to find out whether the transformer has been left disconnected when the system was operated. If a current transformer is not shorted out when it is disconnected from an operating system, extremely high current will flow through the transformer and change its characteristics.

21-61. To determine whether a particular current transformer is causing a load-division problem, it may be necessary to isolate the suspected generator from the system. If the remaining generators operate normally, this indicates that the isolated system was causing the problem.

CHAPTER 6

Motors and Inverters

UP TO THIS point we have discussed means of generating electrical energy. Now it is time to use this energy. Electrical energy can be transformed into mechanical energy. We are able to raise and lower the landing gear, flaps, and even the pilot's seat with mechanical energy.

2. A motor, either ac or dc, is a rotating machine which transforms electrical energy into mechanical energy. A motor, like a generator, consists of two principal parts—a field assembly and an armature assembly. The armature is the rotating part in which current-carrying conductors are embedded. These conductors are acted upon by magnetic fields, which cause them to move and make the armature rotate. The magnetic fields are the fields surrounding either permanent magnets or electromagnets; however, electromagnets are used almost exclusively.

3. Sometime the electrical energy may not be in the form needed for a particular use. That is, the current may be dc when ac is needed. You know that most aircraft have ac generators installed today, but you have not seen the last of dc powered aircraft. The method of changing dc to ac is to invert the dc; therefore the unit is called an inverter. Inverters come in two forms rotary or static—both forms will be covered in the text. An inverter is two items in one. A dc motor drives an ac generator. Voltage and frequency controls are through many methods of which the most common will be discussed. We will start our discussion with dc motors.

22. DC Motors

22-1. Prior to our discussion of dc motors we should have a brief review of the laws of magnetism, which were covered in Volume 1, Chapter 5. At that time we learned that lines of force never cross each other but exist in complete, unbroken paths. Also, there is a magnetic field surrounding any current-carrying conductor. When this conductor is wound in the form of a coil a north and south pole can be established. And, finally, let us again state that like poles repel and unlike poles attract. With these fundamentals in mind, we will begin our discussion on motor principles.

22-2. **Motor Principles.** As we said before, it is possible to apply a voltage to the output terminals of a generator, and the generator will run like a motor.

22-3. *Motor action.* As stated previously a motor operates by a force that is exerted on a current-carrying conductor placed in a magnetic field. The tendency of this force to cause rotation is called torque. Figure 65, part A, shows the forces acting on a single-turn coil conductor in a magnetic field. Current flowing out of the left-hand conductor and into the right-hand conductor establishes magnetic fields around the conductors as shown. This causes a distortion of the magnetic flux. The lines of force from the pole pieces are strengthened below the right-hand and above the left-hand conductors. Likewise, those above the right-hand and below the left-hand conductors are weakened. As the result of the reaction between the magnetic fields, the right-hand conductor tends to move upward, while the left-hand conductor tends to move down. This rotation continues until the conductors reach the position indicated in figure 65, part B. In this position, the forces tend to spread the conductors apart and there is no further torque tending to rotate the coil.

22-4. The problem in the single-coil dc motor is to cause the armature to rotate past the position where the conductors are supposed to move parallel to the magnetic flux of the pole pieces (fig. 65,B). We depend on momentum or inertia to move the coil past this position. Then, to keep the coil moving in the same direction, we use a commutator which reverses the direction of electron flow each time the conductor reaches the no-torque position. In the dc generator, the commutator changes ac in the conductors to dc in the output. The process is reversed in the motor; the dc input is changed to ac in the conductors.

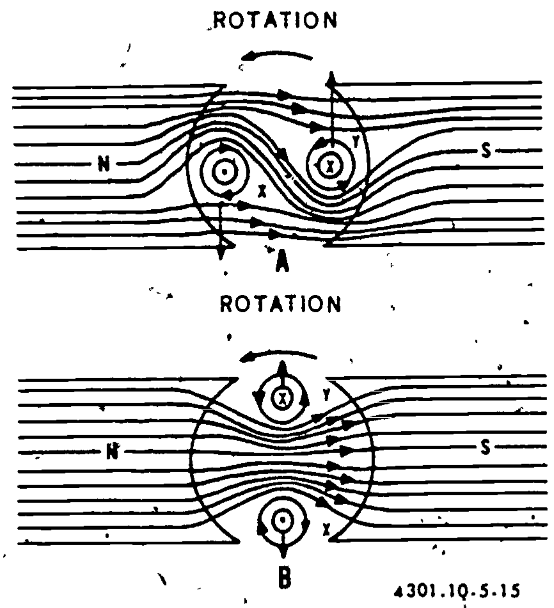

Figure 65. DC motor principles.

22-5. A single-coil motor, even with a commutator, is impractical because of the pulsating torque. A large number of properly spaced coils on the armature will provide a torque that is both steady and strong, regardless of armature position. The construction of a motor armature is the same as that of a generator armature. Additional pairs of poles, as in a generator, are also used. The rotational force (torque) that turns the motor armature depends on two factors—armature current and the strength of the magnetic field. Increasing either increases torque.

22-6. *Counter-electromotive force (cemf).* When the armature in a motor rotates in a magnetic field, a voltage is induced in its windings. This voltage is called the back- or counter-electromotive force (cemf) and is opposite in direction to the voltage applied to the motor from the external source. Cemf opposes the voltage that creates the current which rotates the armature. Figure 66 depicts the voltages present in an operating motor. By application of the left-hand generator rule, you can see that the cemf opposes the applied voltage. Since there must be motion to generate a voltage in the armature winding, cemf is not present until the armature assembly starts turning. The current flowing through the armature decreases as the cemf increases. The faster the armature rotates, the greater the cemf.

22-7. For this reason, a motor will draw a fairly high current when starting, but as the armature speed increases, the cemf generated increases and the current flowing through the armature decreases. At rated speed, the cemf may be only a few volts less than the applied voltage. With this explanation, you can see why the current draw of a motor cannot be determined by the ohmic resistance of the armature. You may find a 28-volt motor with an armature resistance of 0.1 ohm operating on 40 amperes. According to Ohm's law, this motor should draw 280 amperes. However, with the motor in operation, there is a 24-volt cemf developed in the armature. With 28 volts applied and a 24-volt cemf, the effective voltage in the armature is only 4 volts. Then, according to Ohm's law, the current flow is only 40 amperes.

22-8. As a load is added to a motor, the armature speed decreases. When this happens, the cemf decreases, causing an increase in the armature current which will increase the output torque.

22-9. **Types of Motors.** There are three basic types of dc motors—series motors, shunt motors, and compound motors. They differ in the way their field and armature coils are connected.

22-10. *Series motor.* In the series motor, the field windings, consisting of a relatively few turns of heavy wire, are connected in series with the armature winding, as shown in part A of figure 67. The same current that flows through the field winding also flows through the armature winding. Any increase in current, therefore, strengthens the magnetism of the field.

22-11. Because of the low resistance in the windings, the series motor is able to draw a large current when starting. This starting current, in passing through both the field and armature windings, produces a high starting torque, which gives the series motor its principal advantage—high starting torque. This makes the series motor ideal for starter or actuator functions.

22-12. The speed of a series motor depends on the load. Any change in load is accompanied by a substantial change in speed. A series motor will run at high speed when it has a light load

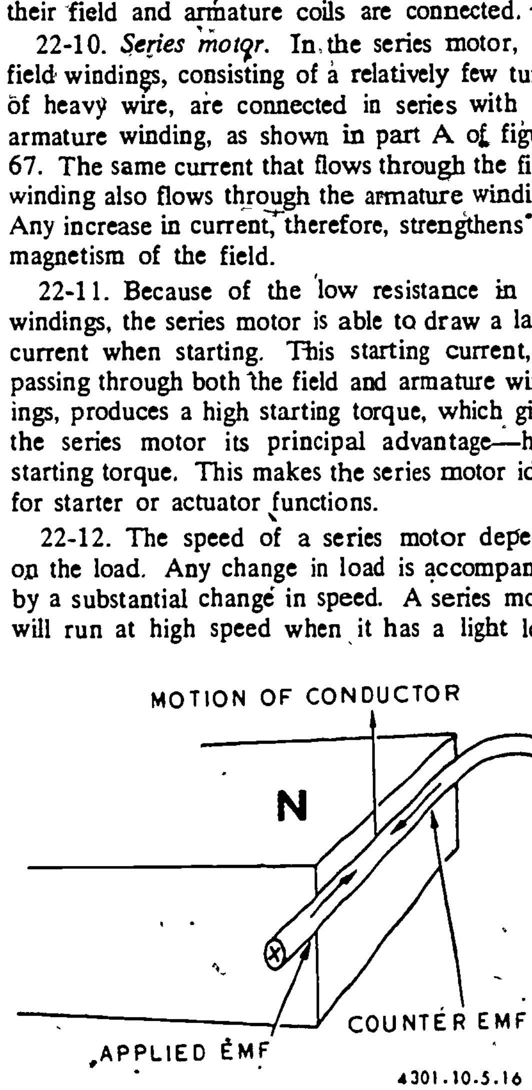

Figure 66. Voltages in a motor armature.

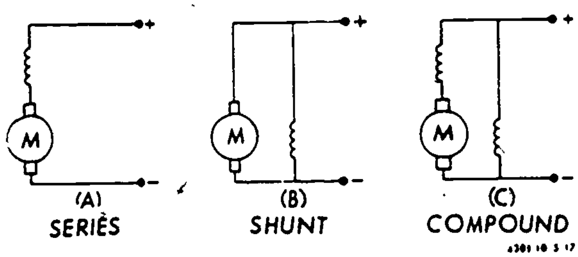

Figure 67. Types of dc motors.

and at low speed with a heavy load. If the load is removed entirely, the motor may operate at such a high speed that the armature will fly apart. For this reason, a series motor is normally bench tested under no-load conditions, at half the rated voltage.

22-13. *Shunt motor.* In the shunt motor, the field winding is connected in parallel, or in shunt, with the armature winding, as shown in part B of figure 67. The resistance in the field winding is high. Since the field winding is connected directly across the power supply, the current through the field is constant. The field current does not vary with motor speed as it does in the series motor, and therefore the torque of the shunt motor will vary only with the current through the armature. The torque developed at starting is less than that developed by a series motor of equal size.

22-14. The speed of the shunt motor varies very little with changes in load. When all load is removed, it assumes a speed slightly higher than the loaded speed. This motor is particularly suitable for use when constant speed is desired and when high starting torque is not needed. This motor may be damaged if the rpm operating rate is too low.

22-15. *Compound motor.* Like the compound generator, the compound motor has both series and shunt field windings, as shown in part C of figure 67. The series winding may either aid the shunt winding (cummulative compound) or oppose the shunt winding (differential compound). The differential compound motor is not used by the Air Force.

22-16. The characteristics of the cumulative-compound motor lie somewhere between those of the series and those of the shunt motor. As the load is increased, the increase in current increases the flux due to the series winding. This increases the torque faster than the increase for a straight shunt motor. But this increase in flux decreases the speed more rapidly than the speed decrease in a shunt motor. The applied and developed torques are balanced with less speed decrease than in a series motor, but more than in a shunt motor, as shown in figure 68.

22-17. Because of the series field, the cumulative-compound motor has a higher starting torque than a shunt motor. Cumulative-compound motors are used in driving machines that are subject to sudden changes in load. They are also used where a high starting torque is desired but a series motor cannot be used.

22-18. **Duty Ratings.** Electric motors are required to operate under various conditions. Some motors are used for intermittent operation; others operate continuously. Motors built for intermittent duty can be operated for short periods only, and then must be allowed to cool before being used again. If such a motor is operated for long periods under full load, the motor becomes overheated. Motors built for continuous duty may be operated at rated power for long periods of time.

22-19. *Continuous.* Motors designed for continuous operation are used on such units as inverters, pumps, and other units which are required to operate over long periods of time.

22-20. *Intermittent.* Motors designed for intermittent operation are used in such systems as wing flaps, special hydraulic pumps, landing gear, and other units which do not require continuous operation.

22-21. **Motor Speed Control.** The speed of a series motor may be controlled by a rheostat connected in any one of the three ways shown in figure 69. When the rheostat is in parallel with the armature (A), increasing the rheostat resistance increases armature current and thereby increases the speed of the motor. When the rheostat is in series with the motor (B), increasing rheostat resistance decreases current flow in the entire circuit and thus reduces motor speed. When the rheostat is connected in parallel with the field (C), increasing rheostat resistance decreases armature current and reduces the speed of the motor.

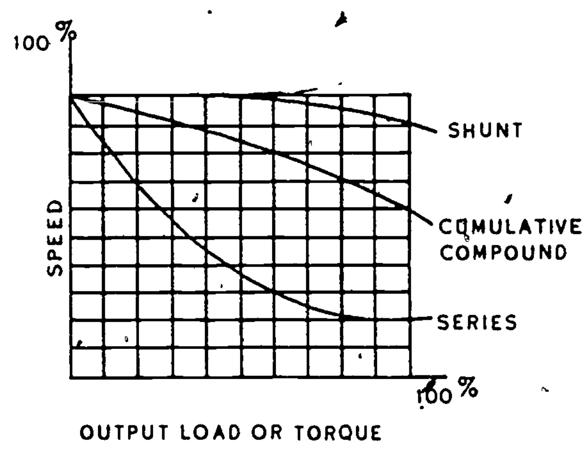

Figure 68. Load characteristics of dc motors.

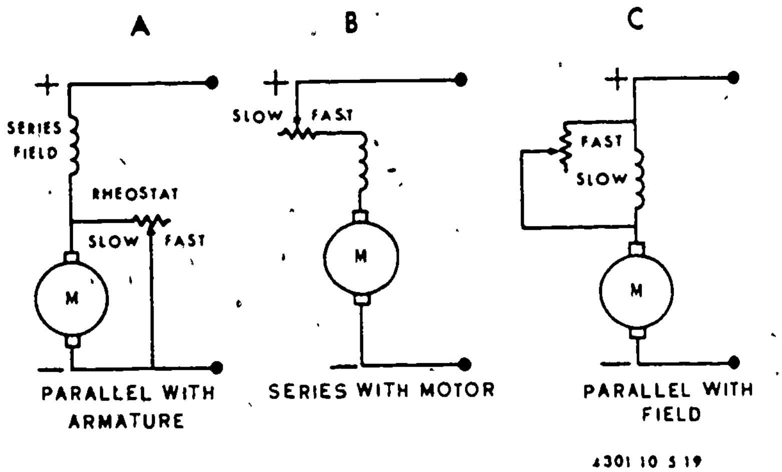

Figure 69. Controlling speed of series motors.

22-22. If the motor is intended to operate at near its normal rated speed, connection B is used. If it is intended to operate at lower than normal speed, connection A is used. Connection C is preferred for operation above normal speed.

22-23. In the shunt motor, speed can be controlled by a rheostat in series with the field windings, as shown in figure 70, part A. The speed depends on the amount of current which flows through the rheostat to the field windings. To increase the motor speed, the resistance in the rheostat must be increased. This decreases the field current. As a result, there is a decrease in the field strength of the field windings and in the cemf. This allows the armature current to increase and the torque to also increase slightly. These increases require no overload condition on the motor. The motor than automatically speeds up until the cemf increases and there is a new balanced condition established between load and armature current. When this occurs, the motor will be operating at a higher fixed speed than before.

22-24. To decrease the motor speed, the resistance of the rheostat must be decreased. More current then flows through the field windings and thus the strength of the field is increased. The cemf then increases and decreases the armature current. As a result, the torque decreases and the motor slows down until a new balanced condition is established between load and armature current. The motor is then operating at a lower fixed speed than before. This method of varying field strength is the most efficient method of controlling shunt-wound motor speed.

22-25. The speed of a shunt motor can also be controlled by a rheostat in series with the armature, as shown in part B of figure 70. In this case, field strength remains constant and armature current is varied. Speed is increased by decreasing rheostat resistance and is decreased by increasing rheostat resistance. When the speed of a shunt motor is adjusted by armature control, the speed regulation becomes very poor at the lower speeds. Also, there is a power loss across the rheostat. For these reasons, field control is more generally used. Armature control is used only where an occasional decrease in speed is required or where the load decreases with the speed as in blowers or fans.

22-26. **Reversing Direction.** The direction of rotation of a motor may be reversed by reversing the direction of current flow in either the armature or the field windings, but not in both at the same time. This will reverse the magnetism of either the armature or the magnetic field in which the armature rotates. If the wires which connect the motor to an external source are reversed, the direction of rotation will not be reversed, since changing these wires reverses the magnetism of both field and armature and leaves the torque in the same direction as before.

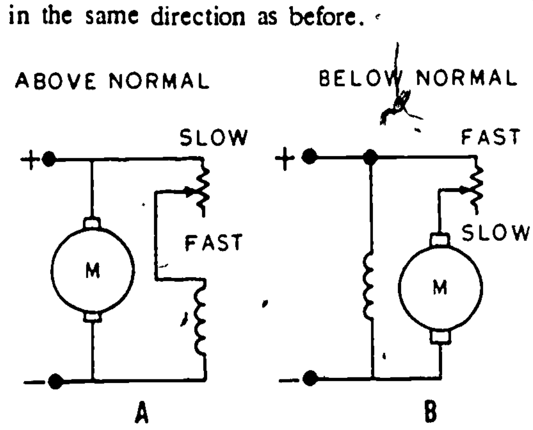

Figure 70. Controlling speed of series motors.

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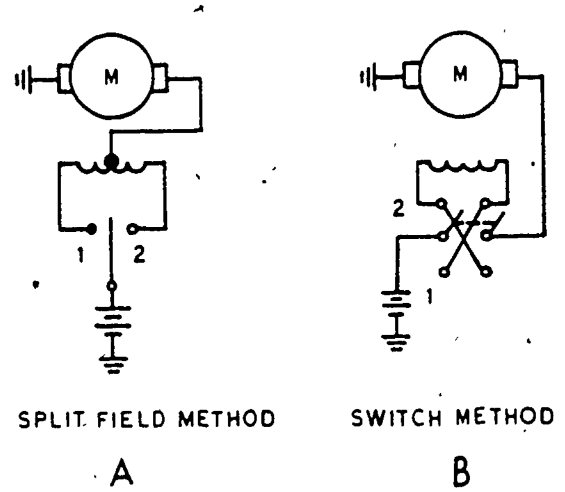

Figure 71. Controlling motor direction.

22-27. *Split-field method.* One method for reversing direction of rotation is the use of two field windings wound in opposite directions on the same pole. This type of motor is called a split-field motor. Figure 71,A, shows a series motor with a split-field winding. The single-pole double-throw switch makes it possible to send current through either of the two windings.

22-28. When you place the switch in the Nr. 1 position, current flows through the left field winding, creating a north pole at the right end of the wounding and a south pole at the left end. When you place the switch in the Nr. 2 position, current flows through the right field winding, the magnetism of the field is reversed, and the armature rotates in the opposite direction.

22-29. Some split-field motors are built with two separate field windings wound on alternate poles. The armature in such a motor, a four-pole reversible motor, rotates in one direction when current flows through the windings of one set of opposite pole pieces, and in the opposite direction when current flows through the other set of windings.

22-30. *Switch method.* Another way to reverse direction is to use a double-pole double-throw switch that can change the direction of current flow in either the armature or the field, as shown in the illustration of the series motor in figure 71,B. Current direction can be reversed through the field, but not through the armature. When the switch is thrown to the Nr. 1 position, current flows through the field winding to establish a north pole at the right side of the motor and a south pole at the left side of the motor. When the switch is thrown to the Nr. 2 position, this polarity is reversed and the armature rotates in the opposite direction.

23. AC Motors

23-1. Ac motors have a number of advantages over dc motors. The three main advantages are less arcing at high altitudes, smaller size, and lighter weight for the same power output. There are two general types of ac motors which are used on aircraft, the induction and the synchronous. The induction motors are further divided into three classes: single-phase, two-phase, and three-phase. Of these, the three-phase is the class generally found on aircraft. Prior to starting our discussion of ac motors, let's discuss one that can be used on either ac or dc.

23-2. **Universal Motor.** A universal motor is a series-connected motor that may be operated on ac or dc with approximately the same speed and torque characteristics. The armature and field coils of the universal motor are connected in series. A change in current direction, due to the ac input, or commutation action of dc results in an in-phase relationship between the armature and the field flux. As the direction of current flow and the direction of magnetic flux in the field and armature are changed, the rotation of the armature will remain the same. Even though the current is reversing 120 times per second (60 Hertz input), the universal motor will continue to run in the same direction, because the field flux is always in phase with the armature flux. When a universal motor is run on dc, the current flowing in the circuit is limited only by its resistance and the self-induced armature voltage. For ac operation, the reactance due to the inductance of the coils absorbs some of the line voltage, resulting in a lower speed on ac than on dc for a given value of current. In large universal motors, reactance losses are compensated for by an auxiliary winding. This winding is displaced 90 electrical degrees from the main field winding. The field of this compensating winding counteracts the effect of armature reaction and also tends to improve commutation. In universal motors, the field and the frame must be laminated to reduce heating by eddy currents when the motor is used on ac.

23-3. These motors are seldom found on aircraft or allied equipment; they are usually used in instrument testing devices. However, they have a wide commercial application. You will come across them in electric drills, fans, and such small appliances as vacuum cleaners.

23-4. **Induction Motors.** The induction motor has long been known for dependable, trouble-free service. This type of motor is used where small and medium-sized ac motors are needed. The speed is determined by the number of poles and the frequency of the supply voltage, and

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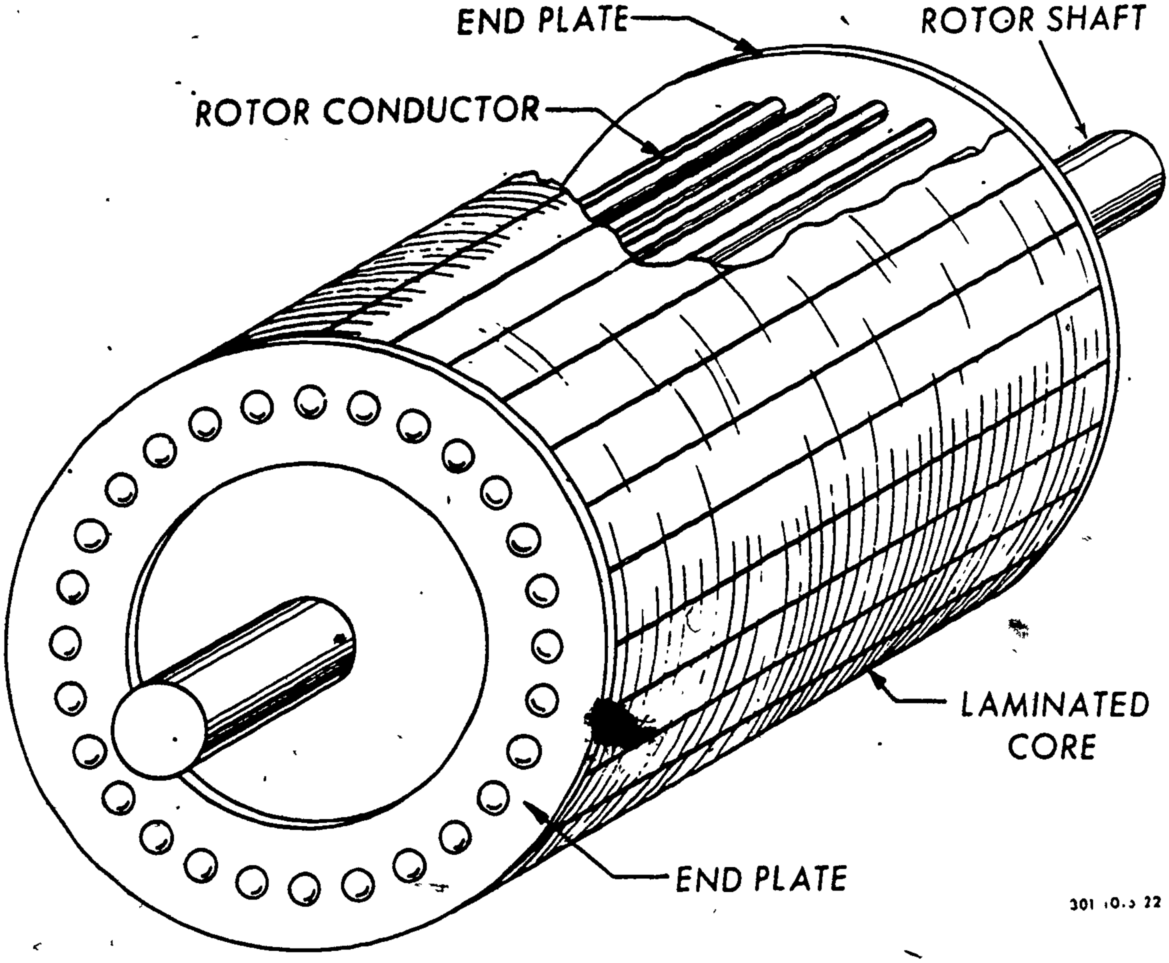

Figure 72. Squirrel cage rotor.

remains constant over a wide range of loads. The induction motor, as the name implies, operates on the same principle as a transformer, with the stator acting as the primary winding and the rotor acting as the secondary. There are no connections between the stator and the rotor; all voltages in the rotor are created solely by mutual induction. We will next discuss the three types of rotors found in induction motors.

23-5. *Squirrel cage rotor.* Some induction motors have a rotor that is called a squirrel cage. The basic construction principles of all squirrel cage rotors are the same regardless of the differences in appearance (see fig. 72). Each is made of a laminated iron core mounted on a spider or framework secured to the shaft. Bars of copper, aluminum, or some alloy which is a good conductor are laid in slots on the core. The bars are welded to end plates at each end of the rotor. That's all there is to it—no electrical connections to outside lines, no insulation, no phases, and no sliprings. This rotor got its nickname from the appearance of the windings when removed from the iron core.

23-6. *Double squirrel cage rotor.* The double squirrel cage rotor contains two sets of rotor bars, as shown in figure 73. One set of bars, which has a comparatively small cross-sectional area, is placed in the slots close to the surface of the rotor; the other set, which has a larger cross-sectional area, is placed deeper into the slots. The set with the smaller cross-sectional area has a resistance of a few tenths of an ohm, while the other set has a resistance of a few thousandths of an ohm. The larger number of flux linkages around the lower conductors gives this set a greater inductance. The high frequency at which the rotating field cuts both sets of conductors at starting speeds causes the total impedance of the low-resistance winding to be higher than the impedance of the top winding. In starting, therefore, most of the current flows through the top bars. The higher resistance of these bars tend to reduce the phase angle between the rotor current and the field flux, and this increases the starting torque. As the rotor comes up to speed, the frequency of the voltage induced in the rotor becomes lower, and the inductive reactance of

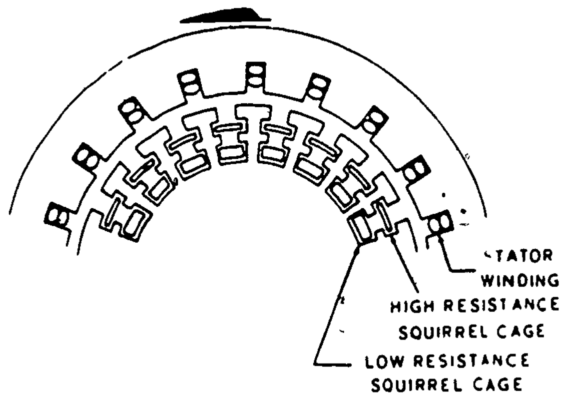

Figure 73. Double squirrel cage rotor.

the bottom bars is reduced. Since the reactance of both sets of bars is relatively low, the current flow is now limited largely by the ohmic resistance of the bars. Most of the current now flows through the bottom bars, since they have the lower resistance.

23-7. Under no-load conditions, the double squirrel cage motor operates as a normal single squirrel cage motor, with most of the current flowing through the bottom bars. Under varying load conditions, the current automatically divides between both sets of bars in the proper proportions to produce the required amount of torque. The double squirrel cage motor has medium high starting torque and moderate speed characteristics. If very high starting torque and moderate speed control are desired, a wound rotor motor is more suitable.

23-8. *Wound rotor.* These motors, as used by the Air Force, are generally operated on three-phase power. The stator is wound in the same manner as the stator of the three-phase squirrel cage motor; the rotor, however, is wire-wound and is connected into three-phase groups. The leads from one end of the three-phase groups are star-connected, and the other three leads are connected to three sliprings, as shown in figure 74. Three rheostats are star-connected, through the sliprings, to the rotor windings. All three rheostats are mounted on one shaft, so that they may all be adjusted simultaneously. The motor is started with the full resistance in the rotor circuit. After the motor starts, the resistance is gradually reduced until it is out of the circuit entirely. The motor is now at full speed. The starting current is not much greater than the full-load current. The wound-rotor motor is a variable-speed motor, since its speed can be controlled by varying the external resistances. Although this type of motor has a higher starting torque than single or double squirrel cage motors, it is not as efficient at running speeds, because it is not possible to have as low a resistance in a wound rotor as in a squirrel cage rotor. This is because the bars in a squirrel cage rotor have less resistance than the wire in the wound rotor.

23-9. *Operating principles.* When an alternating current is applied to the primary of a transformer, a varying magnetic field is established which induces a voltage into the secondary winding. When a voltage is induced in a coil situated in a magnetic field a current flows and the associated magnetic field reacts with the existing magnetic field and a force is set up which tends to produce motion in the coil relative to the field. If the secondary windings were free to move, they would do so; however, they would come to rest as soon as they were outside the influence of the magnetic field. If the secondary is to continue moving, the primary must be moved so as to keep the secondary within the magnetic field.

23-10. To explain how torque is produced, the induction motor may be considered as consisting of a horseshoe magnet and a disk. For purposes of explanation, however, assume that the disk and the horseshoe magnet are both free to rotate on a common axis. Since the pole faces of the magnet are separated from the surface of the disk by only a small airgap, the flux lines of the magnet pass through the disk. As the magnet is rotated, the magnetic field induces eddy currents in the metal disk. These induced currents follow definite paths in the disk, as though they were following through regular conductors. According to Lenz's law, the current induced in a conductor as a result of its motion in a magnetic field is in such a direction as to exert a mechanical force opposing the motion. In the case under consideration, the fact that the disk is initially stationary and the magnetic field is rotating is of no consequence, because all motion is relative. The magnetic field produced by the eddy currents induced in the disk exerts a force that opposes the motion of the magnet. But, since

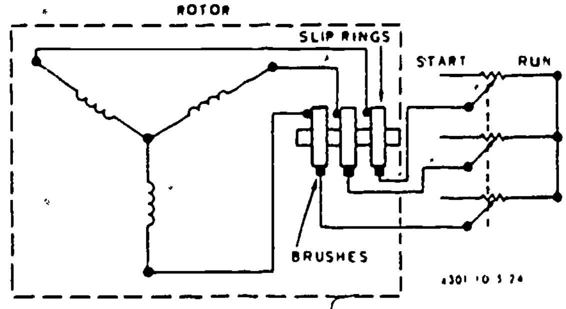

Figure 74. Wound rotor schematic.

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the disk is not held stationary, the opposing force in the disk causes it to revolve.

23-11. In a constant magnetic field, motion of the field or motion of a conductor in the field, will cause current to be induced in the conductor. The direction of the induced current in the conductor will be such that, by its electromagnetic action on the field, it will cause the conductor to move in the same direction as the magnetic field. The magnet and the disk will both be turning in the same direction; however, when the disk is turning more slowly than the magnet, the relative motion of the disk is in the opposite direction with respect to the direction of rotation of the magnet. In other words, if relative motion were maintained between the magnet and the disk, and the magnet stopped rotating relative to an observer, the disk would be rotating in the opposite direction. The relative motion between the magnet and the disk, usually referred to as the slip, is important, because it is this motion which induces the current into the disk to produce the operating torque. As the slip increases, the torque decreases. If the slip action continues to increase, a breakdown torque will be reached, at which point the rotor will come to a standstill.

23-12. The synchronous speed of an induction motor is the speed at which the magnetic field rotates. It depends upon the number of poles from which the stator is wound and the frequency of the applied voltage. Even at no load, an induction motor will not reach synchronous speed, because there must be a difference in relative speed between the stator field and the rotor in order for induction to take place. It is only attained by synchronous motors with dc excited rotors. Before we proceed, you have to learn two formulas—the first is for synchronous speed:

$$\text{Synchronous speed} = \frac{60 \times \text{frequency}}{\tfrac{1}{2}\ \text{Nr. of poles per phase}}$$

The other is for "slip," which is the difference between the speed of the rotating field and the rotor; as you can observe, it begins where the first formula leaves off:

$$\text{Slip in \%} = \frac{\text{synchronous speed} - \text{actual speed}}{\text{synchronous speed}} \times 100$$

This value varies from 4 to 8.5 percent at full load for motors of from 1 to 75 hp. At two to four times its normal rated load, an ac induction motor may be expected to stall. The reason is "breakdown torque," the point at which the rotor is so heavily overloaded that the magnetic field no longer has enough strength to turn the rotor. When this occurs, not only will the rotor stall, but the stator also will overheat in the same manner as an overloaded transformer. Needless to say, this condition is dangerous. For safety, then, always be sure that maximum load limits for an induction motor are never surpassed.

23-13. An induction motor operates in a manner very similar to that of the simple induction motor composed of the magnet and disk, except that it is unnecessary to rotate the stator to obtain a rotating field. There are no pole pieces in the stator of an induction motor. Instead, a distributed winding, similar to the stator of a universal motor, is used. The coil groups in the stator are lap-wound, and these groups are connected so as to produce the desired magnetic poles. Any number of poles may be formed by connecting the coils together properly. The stator core remains stationary, but it produces a magnetic field which rotates as if the entire stator were turning. The ability of magnetic fields to add together or cancel out makes it possible to create smoothly rotating field poles. When the motor is running with no load, the rotor will increase its speed to nearly that of the rotating magnetic field. If the rotor speed equaled the speed of the rotating field, there would be no slip; consequently, no voltage would be induced in the rotor windings, and there would be no torque, because the conductors would be cutting no flux lines. Therefore, the rotor would slow down until there was sufficient slip to develop the necessary torque. In a no-load condition, very little torque is required; as stated previously, under no-load conditions the rotor speed nearly equals the speed of the revolving field.

23-14. **Single-Phased Motors.** If one lead of the three-phase induction motor is disconnected while the motor is running, it will continue to run on two phase. However, it will overheat if the rated load is still carried. If the motor is stopped, it will not start again with one lead disconnected. Thereby hangs a tale. Single-phase induction motors will run when once started, but they won't start themselves.

23-15. When a single-phase winding is excited with a single-phase current, a pulsating field is produced in the stator. The magnetic field changes in all of the poles at exactly the same time and same rate, so no rotating field is produced. A voltage is induced in the rotor—transformer action—but no torque is produced. The motor is merely acting as a transformer—the stator is the primary and the rotor is the secondary. The current flowing in the rotor conductors, due to transformer action, produces a flux which opposes the flux in the stator, just as the ampere

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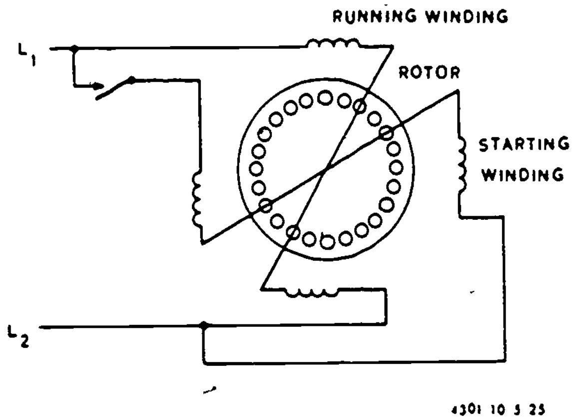

Figure 75. Connections for split-phase motor.

turns of the secondary of a static transformer oppose the primary ampere turns. No torque is developed because of the relative position of the stator and rotor poles. And, there is none during the cycle of current; therefore, no torque is produced by the single-phase motor, and it is not self-starting.

23-16. Since single-phase motors are not self-starting, some auxiliary means must be used to start them. Of course, you could start the very small ones by hand. However, this doesn't solve the problem of starting the larger motors, and it is rather an inconvenient method of starting even the small ones. So some other method is desirable. One method is to split the phase by combinations of inductance, capacitance, and resistance.

23-17. *Split-phase motors.* Figure 75 shows a common method of splitting the phase. Two windings—running and starting—are placed in the stator. The running winding is wound on the stator, and the starting winding is wound on top of it in such a manner that the centers of the poles of the two windings are displaced by 90°.

23-18. The windings are shown schematically in figure 75. Here's the secret to the operation of the split-phase motor—the currents in the two windings are not in phase. The running winding has a low resistance and, being surrounded by iron on all sides except one, it also has a high inductance. On the other hand, the starting winding is wound with smaller wire and has a high resistance. Also, it has iron on only two sides, and consequently has less inductance than the running winding. Therefore, when the same voltage is applied to both windings, the current in the running winding lags the voltage more than does the current in the starting winding.

23-19. Assume that the current in the running winding lags the applied voltage by 50° while the current in the starting winding lags the applied voltage by 30°. The result is a phase difference of 20°. The windings have been already established as being 90° apart; therefore, when the difference is applied to the windings a simulated rotating magnetic field is produced. This is enough of a phase difference to start the motor. The phase difference is not important in this course as a value but rather what the phase difference does for the motor. The phase difference starts the rotating magnetic field which moves the rotor.

23-20. When the motor comes up to speed, a centrifugal device opens a switch and disconnects the starting winding from the line. The starting winding has a high resistance, and the I^2R loss is high. So if the centrifugal device should fail to open the switch, the motor will run hot; if allowed to run very long with the starting winding in the circuit, the winding will be burned out. This is probably the most frequent cause of failure of the split-phase motors.

23-21. *Capacitor motors.* Figure 76 shows a diagram of a single-phase induction motor in which capacitance rather than resistance is used to split the phase. A capacitor placed in the starting winding circuit (part A, fig. 76) causes the current to lead the voltage in the starting winding circuit. By using the proper capacitor, the currents in the two windings—starting and running—can be made to differ in phase by approximately 90°. Then, you have a motor with approximately the same starting torque as a regular two-phase motor.

23-22. Physically, within the motor the two windings are displaced by 90°. With the 90° phase difference of the two currents, the starting torque produced is equivalent to the starting torque of a two-phase motor. Furthermore, the resultant line current is almost in phase with the line voltage, which gives the motor an exceptionally high power factor—almost unity.

23-23. Where a starting winding is used only to start the motor, it is disconnected from the circuit by a centrifugal device when the motor

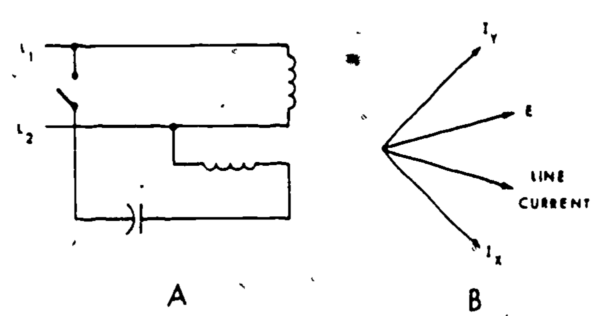

Figure 76. Capacitor start motor.

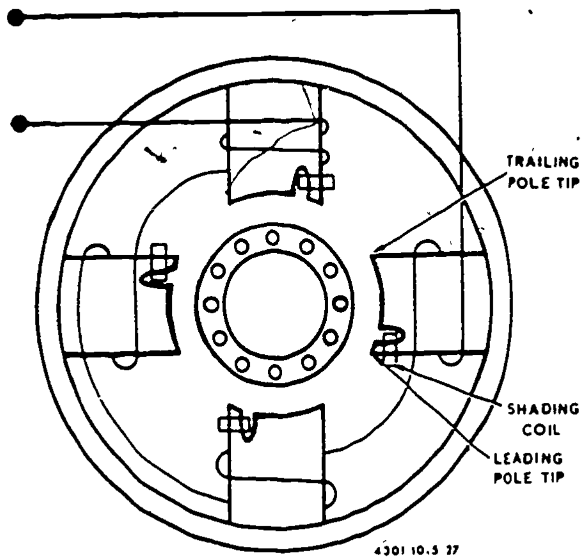

Figure 77. Shaded-pole motor.

gets up to speed. This motor is called a capacitor-start, induction-run motor. However, recent improvements of capacitors and reductions in their costs have made it practical to build motors in which the starting winding in series with a capacitor is left across the line. Thus, the motor operates from a single-phase line with the characteristics of a two-phase motor. To reverse any of the split-phase motors, reverse either the starting winding or the running winding leads.

23-24. *Repulsion-start induction-run motors.* The repulsion motor, in its construction, may be thought of as a combination ac and dc motor. Its stator is similar to that of a single-phase induction motor and its rotor is like that of a dc motor. It is provided with brushes which are shorted together but are not connected to any other part of the motor. When voltage is applied to the stator, a definite polarity is set up in the field poles. This magnetic force will induce a current in the rotor windings. As the current in the stator windings changes direction, so does the induced current in the rotor; the like poles will still be opposite each other and continue the repelling action. As the motor speed builds up, a set of flyweights is put into operation. These flyweights close a short-circuiting device, which removes the brushes from the commutator and then shorts out the commutator segments. This causes the motor to run as an induction motor. The rotor coil will now act the same as the copper or aluminum bars of a squirrel cage rotor. This motor has a very high starting torque and the direction of rotation can be reversed by shifting the brushes 90° E.

23-25. *Shaded-pole motors.* The shaded-pole motor employs a salient-pole stator and a cage rotor. The projecting poles on the stator resemble those of dc machines except that the entire magnetic circuit is laminated and a portion of each pole is split to accommodate a short-circuited copper strap called a shading coil. This motor is generally manufactured in very small sizes, up to $\frac{1}{20}$ horsepower. A 4-pole motor of this type is illustrated in figure 77. The shading coils are placed around the leading pole tip and the main pole winding is concentrated and wound around the entire pole. The four coils comprising the main winding are connected in series across the motor terminals.

23-26. During that part of the cycle when the main pole flux is increasing, the shading coil is cut by the flux, and the resulting induced emf and current in the shading coil tend to prevent the flux from rising readily through it. Thus, the greater portion of the flux rises in that portion of the pole that is not in the vicinity of the shading coil. When the flux reaches its maximum value, the rate of change of flux is zero, and the voltage and current in the shading coil also are zero. At this time, the flux is distributed more uniformly over the entire pole face. Then, as the main flux decreases toward zero, the induced voltage and current in the shading coil reverse their polarity, and the resulting magnetomotive force tends to prevent the flux from collapsing through the iron in the region of the shading coil. The result is that the main flux first rises in the unshaded portion of the pole and later in the shaded portion. This action is equivalent to a sweeping movement of the field across the pole face in the direction of the shaded pole. The cage rotor conductors are cut by this moving field and the force exerted on them causes the rotor to turn in the direction of the sweeping field.

23-27. The shaded-pole motor is similar in operating characteristics to the split-phase motor. It has the advantages of simple construction and low cost. It has no sliding electrical contacts and is reliable in operation. However, it has low starting torque, low efficiency, and high noise level. If is used to operate small fans. The shading coil and split pole are used in clock motors to make them self-starting.

23-28. **Two-Phase Motors.** The two-phase and the four-pole, single-phase induction motors have the same basic construction. However, the coils are not connected together as in the single-phase motor. Since two-phase power has four leads, we simply connect the two leads of each phase to the corresponding phase leads of the power supply.

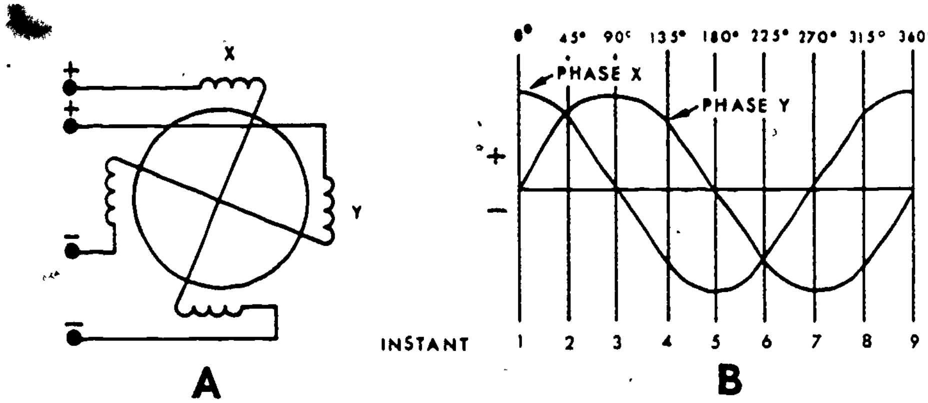

Figure 78. Two-phase motor.

23-29. Figure 78, part A, is a schematic of a two-pole two-phase stator winding. When these windings are energized by two-phase power, the phase relationship of the currents will vary by the sine curves shown in part B. Since there is a 90° phase shift between the phases, no special devices are required to cause a rotating magnetic field in a two-phase motor. It simply follows the output of the ac generator.

23-30. To change direction of the two-phase motor, simply reverse the connection of either of the two phases. This will reverse polarity in one set of poles and cause the magnetic field and the rotor to rotate in the opposite direction.

23-31. On an aircraft, the electrical instruments are just about the only units operated by two-phase motors. The majority of ac motors on aircraft are of the three-phase type.

23-32. **Three-Phase Motors.** The trend of modern aircraft is toward a strictly ac power system. This presents the problem of what type ac motor should be used in the construction of starter and actuator motors. The three-phase motor, because of its small size and light weight, fits the need perfectly. Also, since the three phases are separated by 120 electrical degrees, there is no need for additional starting devices. The induction principles covered for single-phase motors also apply to three-phase motors.

23-33. The direction of rotation of a three-phase motor may be reversed by changing any two of the three power leads. This can easily be done by using a double-pole double-throw relay connected between two of the three motor leads. This relay is then controlled by a remote switch, which controls the direction of rotation of the motor.

23-34. Now we should mention some of the peculiar characteristics of the three-phase motor. Even though it will not always start on two phases, it will run on two phases, but will not carry a very large load. The three-phase motor will not run on one phase. The three-phase motor has a very high starting torque and a great power capability.

23-35. **Synchronous Motors.** The basic parts of a synchronous motor are the rotor and the stator. The rotor is composed of permanent magnets or is one whose poles are excited by a source of dc and whose polarity does not change; the stator consists of several pairs of poles and is excited by ac. A synchronous and a repulsion-start motor operate in much the same manner. In the synchronous motor, however, the rotor polarity is established by furnishing a dc source through the brushes to the rotor windings. By using a multipole stator as in the three-phase induction motors, we can obtain a rotating field when polyphase ac is applied to the stator. When dc is supplied through sliprings to the rotor windings, a fixed polarity is produced at each pole. These poles lock in step with those of the rotating field, and the rotor is pulled around as the stator magnetic field turns. Because of the lockup, the rotor travels at the same speed as the rotating field. In other words, the rotor speed is synchronized with that of the stator field. It is from this design that the motors derive their name.

23-36. Now, let's suppose that the stator and rotor are energized at the same time. According to the laws of magnetism, the stator poles will attract the unlike ones of the rotor. If the motor is a four-pole type and draws 60 Hertz current, the synchronous speed of the field will be 1800 rpm as soon as the field is excited. However, the rotor can't jump from a standstill to 1800 rpm in "nothing flat." The windings would be yanked out of their slots and the entire motor would be wrecked. However, if the rotor is brought up to a speed that is the same or nearly equal to that of the rotating field, it will lock in step and be towed around by the field at synchronous speed. How do we bring this condition about? The

method is simple. We start synchronous motors as induction types. A squirrel cage winding is placed upon the rotor. When the motor comes up to an rpm that is slightly less than synchronous speed, the dc field on the rotor can be excited and the lockup will occur.

23-37. To reverse a synchronous motor, we change the direction of current in the rotor or shift the brushes as we did with the repulsion-start motor. In both cases, we reverse the polarity of the rotor. The synchronous type is used in a few instruments and also electric clocks, but these are about the only devices on aircraft where there is need for such motors.

24. Rotary Inverters

24-1. If you checked the technical order index, you would find there are about one hundred different makes and models of rotary inverters currently installed in aircraft. All have two things in common. These are devices which change dc into 400 Hertz ac, and they consist of a dc motor which drives an ac generator (both of which are mounted in the same housing). A few examples of the differences between the models are the methods of speed control and the frequency control, their ability to generate one or two different voltages, and their electrical capacity. Also, some are single-phase and others are three-phase inverters.

24-2. **Inverter Capacity.** Our first consideration concerns the system for rating the output. The electrical capacity of these units is expressed in volt-amperes. It is equivalent to the product of the voltage produced multiplied by the current capacity, which varies from 100 va to 5000 va for those inverters now in use. In those inverters which produce two different voltages, the capacity is expressed as the sum of the capacity of the two separate sources. For example, an inverter listed as a 250 va, whose output is distributed 60 va at 26 volt, single-phase, and 190 va at 115 volt, single-phase. Another inverter is rated at 750 va at 115 volt, three-phase, and 250 va at 26 volt, single-phase, which results in an inverter with a capacity of 1000 va.

24-3. **Frequency Control.** When dealing with ac, frequency is very important. If the motors, instruments, amplifiers, and other control are to operate efficiently, it is absolutely necessary that the frequency of the voltage be regulated within certain limits. The general range for inverter frequencies is from 375 to 425 Hz, but certain types have controls which maintain frequency between much narrower limits. For example, the frequency range of one inverter is 380–420 Hz, while that of another inverter is 390–410 Hz.

24-4. As indicated previously, frequency is dependent upon two factors. With a two-pole field and a single loop of wire rotating in that field, we know that it is possible to obtain one cycle of ac for each revolution. Now, if the number of fields is increased to eight, we will get four cycles of ac per revolution. If the speed in the latter case were one revolution per second, we would have a frequency of 4 Hz. If the rotating member were driven at a speed of 100 revolutions per second, the induced voltage would reach a frequency of 400 Hz. The formula, as previously mentioned, used for determining frequency is:

$$\text{Frequency} = \frac{\text{Nr. of pairs of poles} \times \text{rpm}}{60}$$

24-5. Since the number of pairs of poles is determined by the unit manufacturer, no control may be exercised there. However, the speed of the inverter is controllable. In some of the smaller inverters the manufacturers have designed motors to run at a fairly constant speed of such magnitude that the inverter will generate a 400 Hz voltage. However, in the larger output inverters there must be some mechanical or electrical control in order to maintain constant speed of the drive motor.

24-6. How, then, is frequency controlled? Well, there are four different ways. You can use either (1) flyweight assemblies, (2) flyweight controlled carbon piles, (3) series resonance circuits, or (4) voltage regulator circuits.

24-7. *Flyweight assembly.* Several inverters include as part of the speed control a flyweight arrangement located at the end of the armature shaft. Under the action of forces resulting from rotation (centrifugal force), the flyweights are forced outward from the shaft. In those inverters having flyweight governors, the outward movement of the flyweights is changed to a lateral motion and applied to a moving electrical contact. A fixed electrical contact is so positioned with respect to the movable one that neither touch when the motor is turning at speeds below the normal frequency range. However, as the motor speed increases, the centrifugal force acting on the flyweight produces progressively more and more lateral displacement of the moving contact. When the speed reaches a point that has the frequency of the inverter at the upper end of the normal frequency range, the contact points touch and complete an electric circuit, which, in turn, acts to reduce the speed of the motor. When this last action occurs, the effect on the flyweight governor unit is lessened and the contacts separate again. As a result, the motor speed

will increase and the cycle will be repeated. Thus, the speed of the motor is regulated so that the frequency of the ac produced by the inverter unit will be within the 375 to 425 Hz range.

24-8. *Flyweight controlled carbon pile.* The carbon pile for this method is similar to the one used in the voltage regulator. We know that carbon is a conductor of electricity and that its resistance is dependent upon the temperature of the carbon and the amount of pressure applied between the various particles. Figure 79 is a drawing of a typical carbon-pile speed control unit. The unit continues to use the rotating flyweight assembly which is counteracted by a ball thrust unit. This ball thrust unit is attached to a glass or porcelain insulating rod, which extends through the carbon pile. One end of the stack of carbon discs is stationary, whereas the washer at the other end is free to move on the insulating rod under the action of a floating stud. You adjust the speed and inverter frequency by turning the nut and varying the pressure on the spring that is located between the nut and the floating stud.

24-9. When the motor turns, the flyweight assembly rotates. This action results in centrifugal force, causing the weights to move outward from the axis of rotation. As the spring member, situated in the governor section, tends to become flat on account of the previous actions, the ball thrust unit moves in the same direction because of the spring in the adjustment end. The first small part of the travel of the assembly produces no control over the motor speed, because the floating stud is not in contact with the movable washer. However, as the speed increases, the lateral movement of the center assembly continues until the floating stud begins to press upon the movable washer. As the acceleration causes more and more pressure to be applied to the stack of carbon discs, the resistance of the carbon stack becomes less, thereby allowing more current to flow in the control section of the inverter motor. When the inverter frequency approaches the upper limit of its normal range, the flow of current through the control field of the motor will be sufficient to bring about a speed reduction. Then the return spring under the flyweights will cause the moving parts to be displaced, the pressure on the carbon pile to be reduced, and the resistance in the control field circuit of the motor to be increased. Units of this design are generally

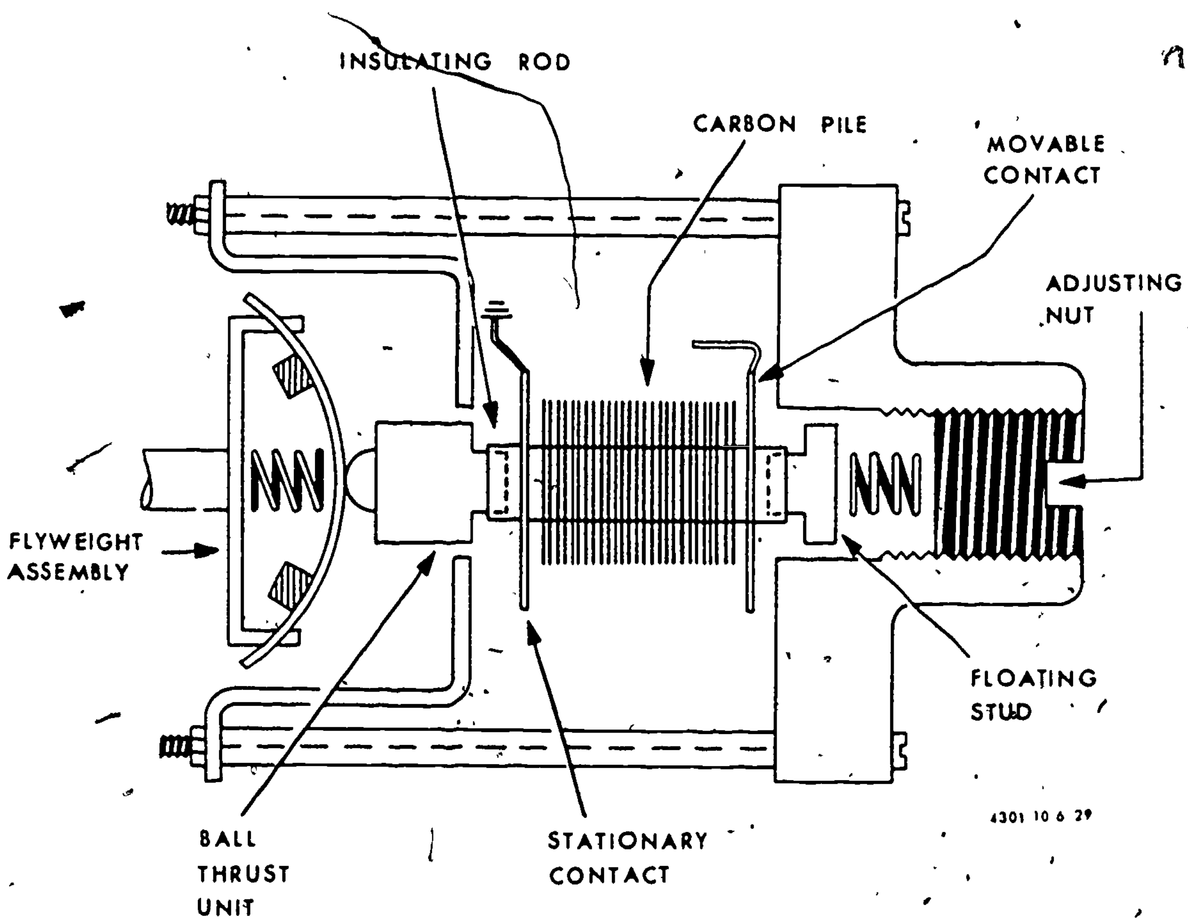

Figure 79. Speed control unit.

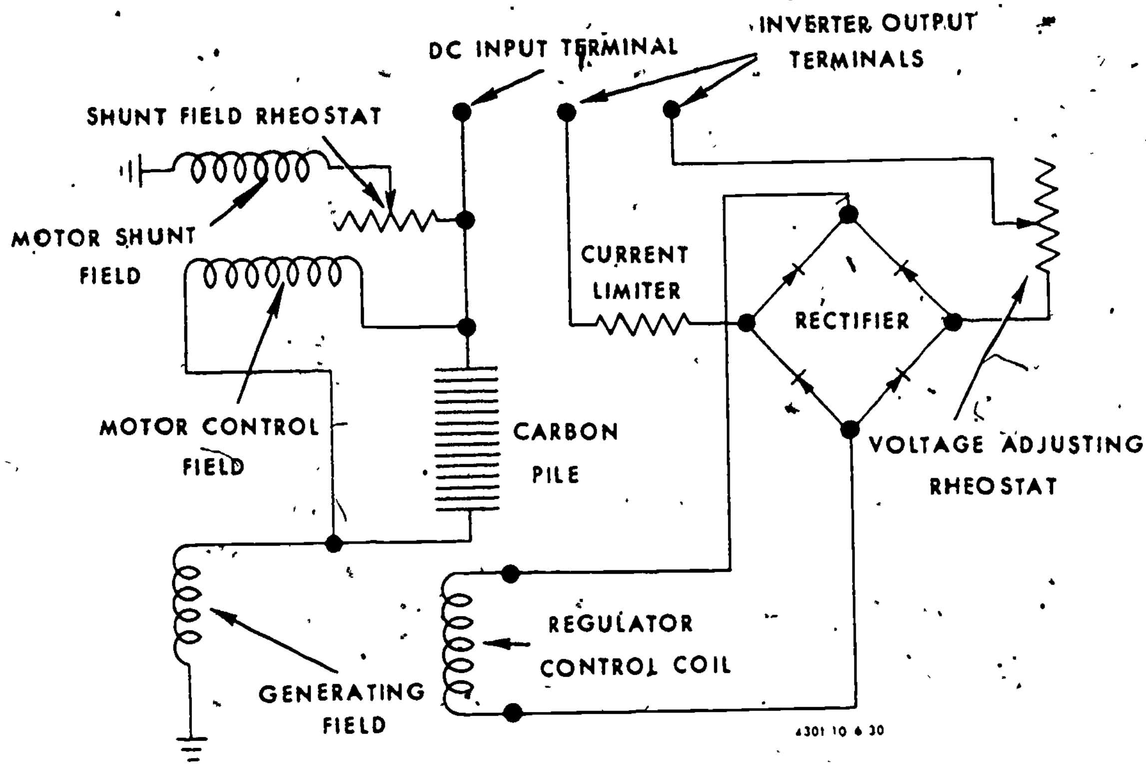

Figure 80. Voltage-regulated speed control circuit.

capable of maintaining the frequency within a range of 380 to 420 Hz.

24-10. *Series-resonance circuit.* The series-resonance principles discussed in Volume 1, Chapter 6, can be applied to this circuit. Its components consist of an inductance coil, a capacitor, a rectifier circuit, and the control field of the inverter motor. The power to operate the circuit is generally furnished by the 26-volt output of the inverter, although in some units it is taken directly from the 115-volt terminals and reduced by use of a transformer. Normally, there is so much impedance offered by the inductance coil and capacitor in the control circuit that very little current will flow through the control field of the motor. However, as the frequency of the current goes above 400 Hz, the circuit will approach a series-resonant condition. At this point, the impedance of the circuit is decreasing rapidly, thus allowing more current to flow through the control field and causing the motor to slow down. As soon as the output reaches 400 Hz, the impedance of the control circuit will again increase and cut down the current in the control circuit.

24-11. *Voltage-regulator circuit.* The frequency-control circuit is connected directly to the voltage-regulator circuit of the inverter, as diagrammed in figure 80. The voltage adjusting rheostat is connected through a rectifier bridge and current limiting resistor to the inverter output terminals. In the rectifier bridge the ac is changed to a pulsating dc, which flows through the voltage regulator control coil, a carbon pile type voltage regulator similar to those previously discussed. The carbon pile is positioned between the dc input terminal and the generating field. Connected in parallel with the carbon pile is the inverter motor control field.

24-12. Normally the voltage adjusting rheostat is factory or depot adjusted to maintain 115-volt ac output. Automatic speed control is obtained through the rectifier, the voltage regulator, and the control field. Any increase in speed above normal will cause the ac voltage to become greater and will put a larger dc voltage across the terminals of the rectifier bridge. As this voltage is impressed upon the regulator control coil, it will cause the pressure on the carbon pile to be decreased. Because of this, there is a corresponding increase in the resistance of the assembly, and, as a result of this action, current flow to the generating field will decrease. Therefore, the ac voltage remains more or less constant in spite of the step-up in velocity. As the resistance of the carbon stack increases, the resistance of the motor control field, which is wired in parallel with the carbon stack, remains the same. This set of conditions causes the current flow through the control field winding to increase and

results in a reduction of motor speed. As the speed of the inverter decreases, the resistance of the carbon pile is lessened. This allows the current to the motor control field windings to decrease. At the same time, the current through the generating field windings will increase, thereby maintaining the voltage.

24-13. Factory and depot adjustments determine the basic speed of motor rotation, and are made only to the shunt field rheostat, which controls the current through the shunt field of the motor. The circuit described above then controls the speed within a narrow range on either side of the factory or depot basic adjustment. Just as frequency can be controlled, so can voltage.

24-14 **Voltage Control.** All of the inverters in use today draw dc power from the motor supply terminals and apply it to the generator field windings through some control medium. Direct current from the motor terminals is used for the field excitation to provide a more constant output voltage. If part of the ac output of the inverter were to be rectified and used for this purpose, you would have to use more filters to smooth out the ripples and eliminate their adverse effects upon the waveform of the output voltage. In the case of the smaller inverters, which operate at a constant speed and upon which the load is fairly light, the strength of these magnetic fields does not have to undergo any appreciable change; therefore, the field current and the output voltage can be controlled through a variable resistor connected in series with the generating field. With a motor speed and a field strength that remains the same, we will always have a constant voltage output as long as the electrical load applied to the inverter is not sufficient to cause a loss in speed.

24-15. Some inverters are equipped with a HI-LO switch. The 115-volt winding is tapped so that additional turns may be switched into the circuit to compensate for a drop in voltage when a heavy load is placed on the system. Usually the HI-LO switch is mounted on the center frame of the inverter and is safetied in one position or the other, depending upon the aircraft and the load the inverter is to carry. The inverter will maintain an output of 115 volts at one-half of full load when the switch is in the LO position, and three-fourths of the 115 volts at full-rated

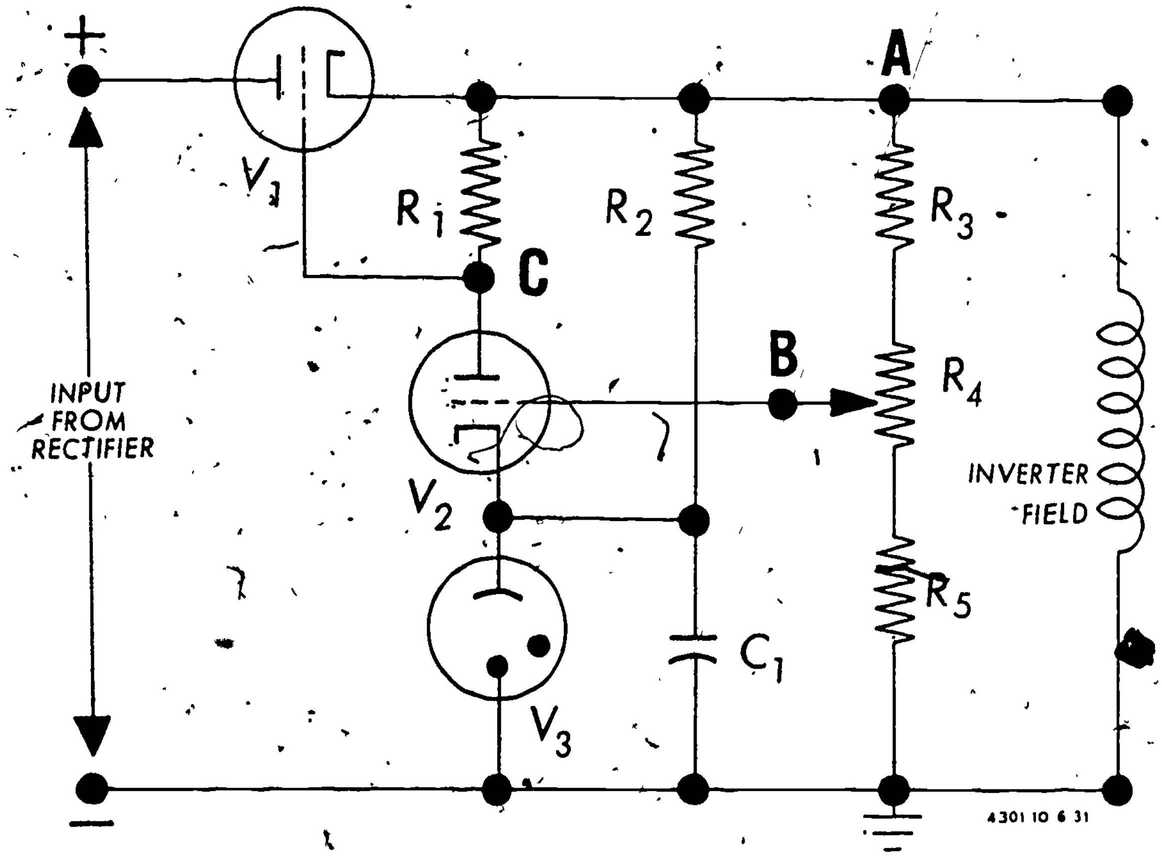

Figure 81. Electronic voltage regulator.

load when the switch is set in the HI position. Although this is a wide variation in voltage, these inverters are installed only when the normal load is less than half of their full capacity. So, with the switch on LO, a fairly constant 115-volt output is obtained from the inverter.

24-16. Most of the larger capacity inverters use a voltage regulator, which senses the output ac voltage (either 26 or 115 volt), transforms it into dc through the use of rectifiers, and then uses this rectified dc to control the current going to the generating windings. In this manner, a more constant voltage is obtained throughout the full load range of the unit. The regulators may be the carbon pile type previously discussed or electronic ones which we will explain next.

24-17. **Electronic Voltage Regulators.** Electronic voltage regulators operate on the principle that a vacuum tube functions as a variable resistor. When a tube conducts, its dc plate resistance is the plate-to-cathode voltage divided by the dc flowing through the tube. An increase in bias decreases the current flow and increases the dc plate resistance of a tube; a decrease in bias increases the current flow and decreases the dc plate resistance of a tube.

24-18. The electronic voltage regulator shown in figure 81 is capable of very close regulation at a level which may be set by varying the potentiometer setting. This circuit contains a vacuum tube V_1 in series with the load (inverter field). The voltage across the inverter field is regulated by controlling the conduction of V_1. Thus, V_1 acts as a variable resistor that automatically adjusts itself to the correct value. V_3 is a VR (voltage regulator) tube, which maintains the cathode of V_2 at a fixed, positive potential. The voltage divider system—composed of R_3, R_4, and R_5—is arranged so the adjustable arm of R_4 can be adjusted to a positive value sufficiently low to bias V_2, so that it operates on the linear portion of the E_g-I_p curve. R_1 is the plate load resistor for V_2, which is connected in series with VR tube V_2. The purpose of this resistor is to absorb any changes of voltage and keep the cathode of V_2 at a fixed potential.

24-19. If the output voltage (point A) tends to rise due to an increase in output voltage, the voltage at point B also tends to rise. The voltage at B is the voltage applied to the grid of V_2 and therefore determines how much V_2 will conduct. If V_2 conducts more, there is an increase in current through R_1 and a decrease in voltage at point C. This decrease in voltage is applied to the grid of V_1 and causes it to conduct less. This increase in the resistance of V_1 counteracts the tendency of rise in output voltage and keeps the voltage constant.

24-20. If the output voltage should tend to fall, the voltage at B tends to drop, causing a rise in voltage at point C. This increase in voltage at C causes V_1 to conduct more and increases the output voltage.

24-21. The setting of B determines the bias of V_2 and therefore the current flowing through it. As this current flows through R_1, it determines the bias on V_1. The dc plate resistance of V_1 determines the output voltage. Consequently, the output voltage is adjustable, within limits, by setting the movable tap, point B, of potentiometer R_4. Because of the great amount of current flow required in some equipment, you may find two or more tubes in parallel to serve the purpose of V_1.

24-22. This regulator is a typical electronic voltage regulator, and there are several variations which appear in inverters of different manufacturers. If you understand this one, you will have no trouble with its variations.

24-23. There are two inverters to insure continuous and accurate operation for certain indicating and control installations that require ac power. One is the "main" inverter, so called because it is in constant operation; the other is an alternate. In order to guarantee the necessary ac power to all units that draw current from the inverter, a changeover relay is installed between both inverters and the units that receive the power. The alternate inverter will automatically assume the load in case the main inverter fails. Normally, in the system containing two inverters, the alternate remains inoperative unless there is an emergency. Or, if necessary, the alternate can be wired so that it is actively functioning at all times.

25. Static Inverters

25-1. Static inverters are completely solid state electronic devices that convert a direct current input into a sinusoidal alternating current output. Those designed for aircraft use normally produce an output of 115 volts and oscillate at 400 Hz. This output can be either single phase or three phase. For simplicity, this discussion will be limited to a particular single-phase design. However, most of the basic concepts are applicable to the other types of static inverters.

25-2. This static inverter, from an input of 27.5 volts dc, produces a single phase, 115-volt, 400 Hz output. The entire circuit (see foldout 3) is composed of six basic circuits which are as follows:

Oscillator circuit (fig. 82)
Voltage sensing circuit (fig. 83)

Voltage reference circuit (fig. 84)
Voltage driver circuit (fig. 85)
Push—pull output circuit (fig. 86)
Resonant output tank circuit (fig. 87)

In our discussion of the static inverter we will use foldout 3 as well as the figures of the six basic circuits that make up the static inverter. We will start our discussion with the oscillator circuit, figure 82 and foldout 3.

25-3. **Oscillator Circuit Frequency Control.** Transformer T1 and transistors Q1 and Q2 make up the oscillator circuit (see fig. 82). This circuit has a constant frequency output of 400 Hz (see waveform 2), and is a push-pull type oscillator. However, push-pull operation of transistors Q1 and Q2 provide greater output than the single-ended transistor oscillator. Dc power for this circuit is provided from an external 27.5-volt dc power supply through the filtering network consisting of reactor L1 and capacitor C7 (see foldout 3). Base bias for the transistors is established by the resistive bridge network consisting of resistors R1, R2, and R3. Resistor R4 is a swamping resistor for temperature stabilization. The frequency of oscillation is essentially determined by the LC tank circuit consisting of capacitor C1 and the primary winding of transformer T1. A regenerative feedback signal is applied between the emitter-base junctions of each transistor by

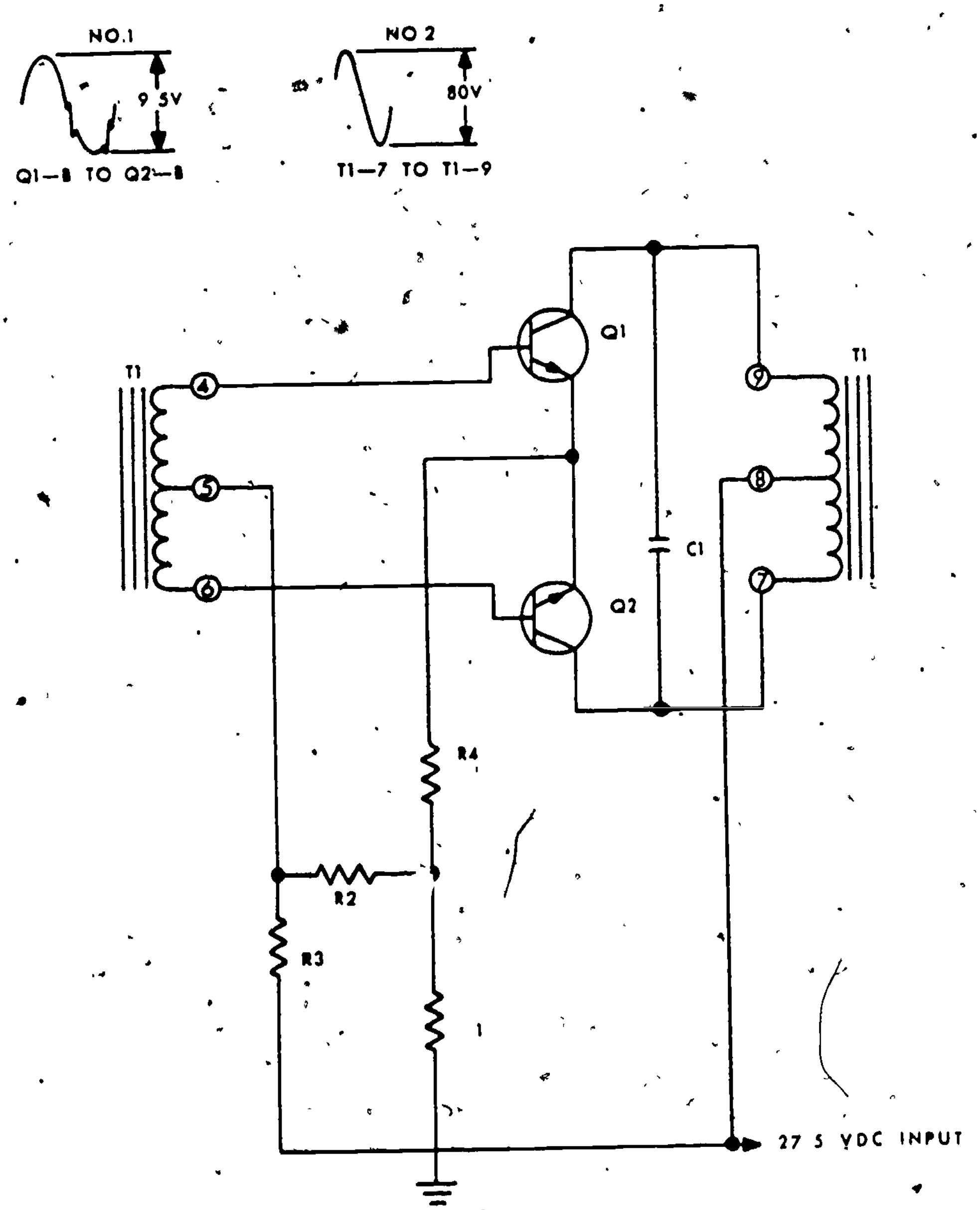

Figure 82. Oscillator circuit.

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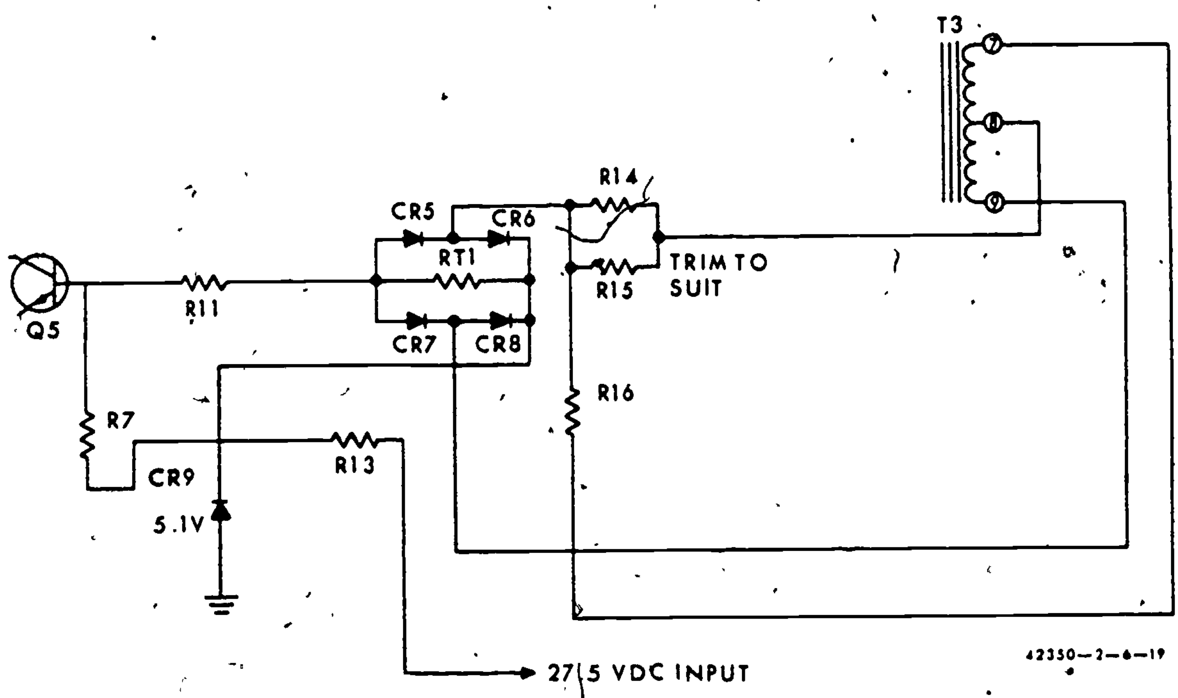

Figure 83. Voltage sensing circuit.

means of the induced voltage in the secondary of transformer T1. Operation of this circuit after feedback is similar to that for the push-pull amplifier. The output of this circuit is coupled to the voltage driver circuit through another secondary winding of transformer T1.

25-4. There are actually two different signals applied to the voltage driver circuit. Both of these signals must be established before you can proceed with the analysis of the voltage driver circuit. One is the sinusoidal output of the oscillator circuit, which has already been discussed, while the other is a dc voltage established by the voltage reference circuit. Because the voltage sensing circuit controls the voltage reference circuit, the sensing circuit is the logical place to proceed with the discussion.

25-5. **Voltage Sensing Circuit.** The voltage sensing circuit establishes the input signal to the voltage reference circuit from a sample of the inverter output voltage. It is comprised of a secondary winding of transformer T3 and a full-wave bridge rectifier consisting of diodes CR5, CR6, CR7, and CR8 (see fig. 83). The inverter output through transformer T3 is impressed across the diode bridge between the junctions of diodes CR5 and CR6 and diodes CR7 and CR8. A constant potential is applied to one side of the bridge while the current through resistor R11 determines the voltage on the opposite side. Therefore, this current, which is proportional to the output of transformer T3, will effect the voltage at the base of transistor Q5 in the voltage reference circuit.

25-6. For the purpose of explanation, assume that the output of the inverter is zero. Therefore, the voltage induced into the secondary of transformer T3 will also be zero as will be the voltage impressed across the diode bridge. There is a constant 5.1 VDC (established by diode CR9) applied to the junction of diodes CR6 and CR8 and resistor RT1. However, there will be a small amount of current through the emitter base junction of transistor Q5 and resistors R11 and RT1 that is sufficient to cause all diodes in the bridge to be reversed biased. At this time the potential at the base of transistor Q5 will be at its maximum positive value, which will forward-bias its emitter-base junction.

25-7. As the inverter output voltage increases, the secondary output of transformer T3 will increase, resulting in a proportional increase in the voltage across the diode bridge. Assume that for a given alternation the instantaneous polarity is such that the junction between diodes CR5 and CR6 is negative with respect to the junction between diodes CR7 and CR8. As the magnitude of the output voltage increases, diodes CR5 and CR8 will become forward-biased but diodes CR6 and CR7 will remain reverse-biased. At this time current flows from terminal 7 of transformer T3 through diode CR5, resistors R11 and R7, diode CR8, and back to terminal 9 of the transformer. When this occurs, the positive potential at the

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base of transistor Q5 will decrease. This decreases forward-bias of its emitter-base junction. On the next alternation, when the polarities of the instantaneous voltages are reversed, diodes CR6 and CR7 will be forward-biased and diodes CR5 and CR8 will be reverse-biased. However, current through resistor R11 will be of the same sense and magnitude as discussed above.

25-8. Whenever the inverter output voltage changes the voltage sensing circuit detects this change. From it a signal is developed such that, when applied to the input transistor (Q5) in the voltage reference circuit, the transistor's emitter-base bias is changed. How this effects the voltage reference circuit will be seen from the following discussion.

25-9. **Voltage Reference Circuit.** The voltage reference circuit is made up of transistors Q5 and Q6 and their associated circuitry (see fig. 84). This reference circuit provides a dc reference voltage for the sinusoidal input signal applied to the voltage driver circuit. This voltage, which is the collector voltage of transistor Q6, is determined by the emitter-base bias of transistor Q5 and Q6. As you have already seen, this bias was the result of a signal developed by the voltage sensing circuit.

25-10. To illustrate the operation of this circuit, assume again that inverter output is zero volts. At this time recall that the voltage to the base of transistor Q5 was at a maximum positive value. This provides a maximum forward-bias for the emitter-base junction of transistor Q5. Therefore, the emitter-base junction of transistor Q6, which is directly coupled to transistor Q5, will also have a maximum forward-bias. This will cause the collector voltage of transistor Q6, which is also the reference voltage applied to the center top of transformer T1, to be at a minimum (near zero) value.

25-11. As you have seen, the voltage reference circuit establishes a dc voltage at the input of the voltage driver circuit. This voltage changes as the inverter output voltage changes. It will be shown in later discussions that a change in the reference voltage causes a change in the magnitude of the inverter output voltage. Therefore, this

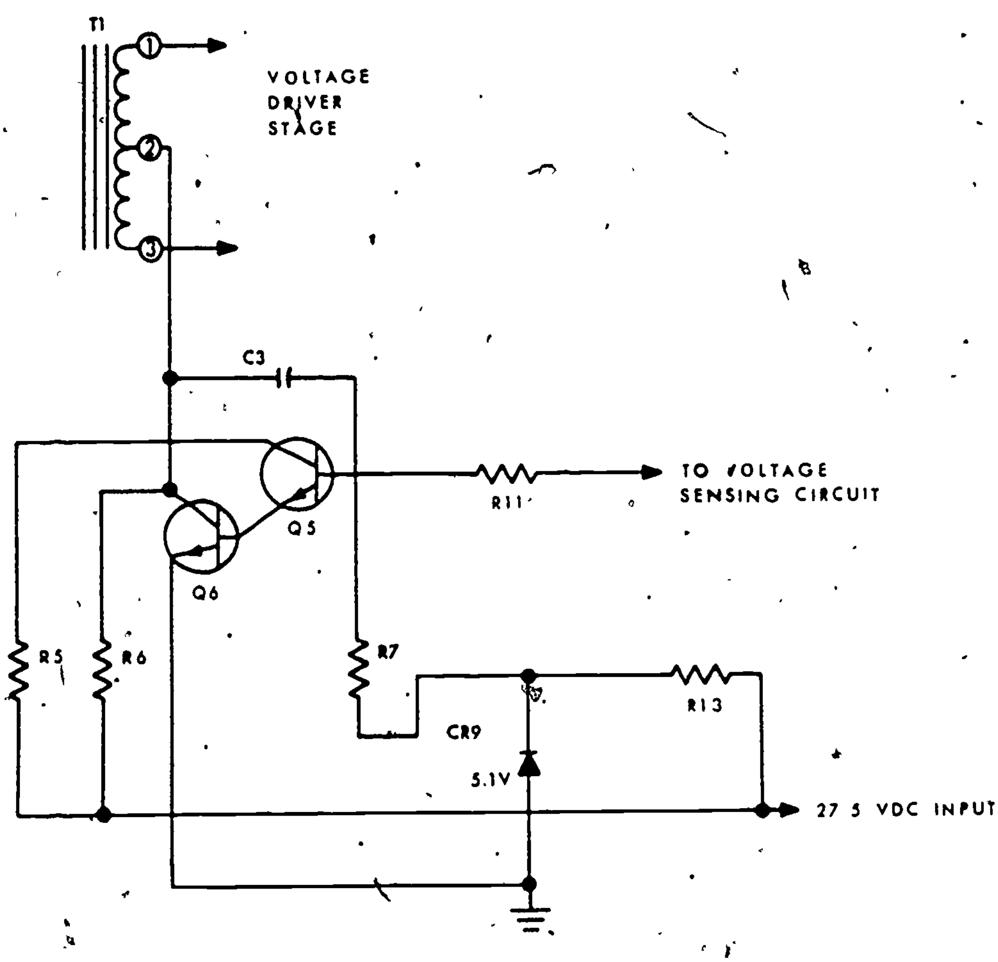

Figure 84. Voltage reference circuit.

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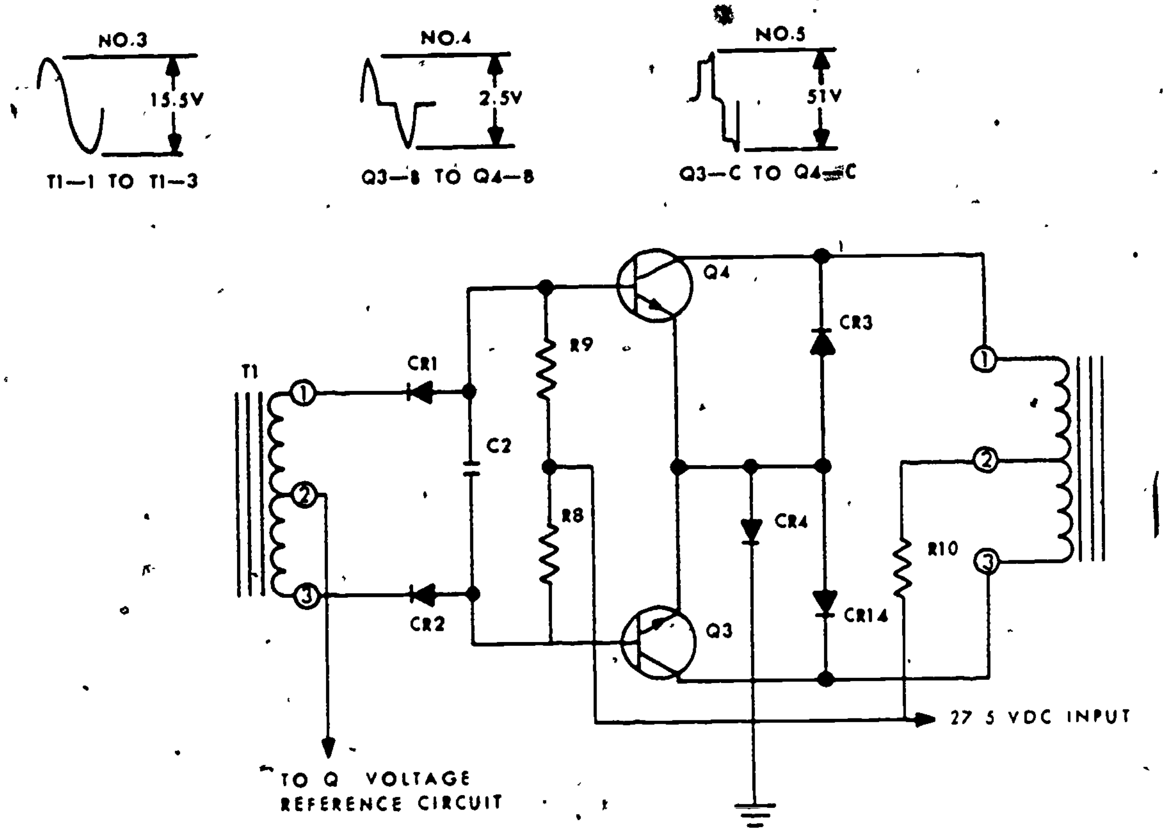

Figure 85. Voltage driver circuit.

circuit combined with the voltage sensing circuit forms a degenerative feedback circuit.

25-12. **Voltage Driver Circuit.** The voltage driver circuit consists of a portion of transformers T1 and T2, transistors Q3 and Q4, and associated components (see fig. 85). This driver circuit is an intermediate stage of amplification. The sinusoidal output of the oscillator circuit is coupled to the input of the voltage driver circuit through transformer T1. This signal (see wavefrom 3) is superposed with the reference voltage at the center tap of transformer T1. Then the resultant signal (see waveform 4) is applied to the bases of transistors Q3 and Q4 through diodes CR1 and CR2. The output from this section is a square pulse (see waveform 5) of constant amplitude but whose pulse width can vary.

25-13. In order to understand this circuit it is best to first compare the output waveshape to the operation of transistors Q3 and Q4. Transistor Q3 and Q4 are biased so that one of the following three conditions can exist.

a. Both transistors conducting at a maximum.

b. Transistor Q3 conducting at a maximum with transistor Q4 cut off.

c. Transistor Q4 conducting at a maximum with transistor Q3 cut off.

25-14. In the first condition, both transistor circuits are conducting at saturation due to clamping diodes CR3 and CR4, this is the quiescent state. At this time, the collector voltages of both transistors will be at their lowest values. However, it should be noticed that the voltage drop of resistor R10 will be large since its current is the sum of both collector currents. This condition is the midpoint of the output waveshape.

25-15. Assume that transistor Q3 is conducting with transistor Q4 cut off. The collector voltage of transistor Q4 will increase to a value approximately equal to the voltage drop of resistor R10. This should be approximately one-half its quiescent value. Notice that the polarities of the collector voltages are such that the collector of transistor Q4 will be positive with respect to the collector of transistor Q3. This condition is represented by the lower pulse of the output wave.

25-16. When transistor Q4 is conducting with transistor Q3 cut off, the previous condition is just reversed. Also, you should note that the polarity of the collector voltages will be reversed. This is represented by the upper pulse of the output wave.

25-17. Now that the operating conditions for transistors Q3 and Q4 have been established, we

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are able to proceed with our discussion. Again, assume that the output of the inverter is near zero. Also, recall that for this condition the reference voltage was approximately zero, thereby placing terminal 2 of transformer T1 effectively at a ground potential. For explanation purposes, assume that the instantaneous voltage of the sinusoidal input signal is such that terminal 1 of transformer T1 is positive with respect to terminal 3. For this set condition, diodes CR2 and CR1 will be forward-biased and reverse-biased respectively. This reverse-biases the emitter-base junction of transistor Q3 cutting it off. It remains cutoff throughout most of the input alternation. As you have already seen, this produces the upper pulse of the output signal. However, the width of the pulse is approximately the same width as the input alternation. On the next alternation, transistor Q4 will be cut off, producing the lower pulse of the output signal.

25-18. As the inverter output voltage increases, the reference voltage applied at terminal 2 of transformer T1 increases. The sinusoidal input signal is then superposed on the reference voltage and applied to diodes CR1 and CR2. This will cause each diode to conduct for a shorter period of time during each input alternation, which reduces the width of each pulse (but not the frequency) that is alternately applied to the base of each transistor. The pulse width of

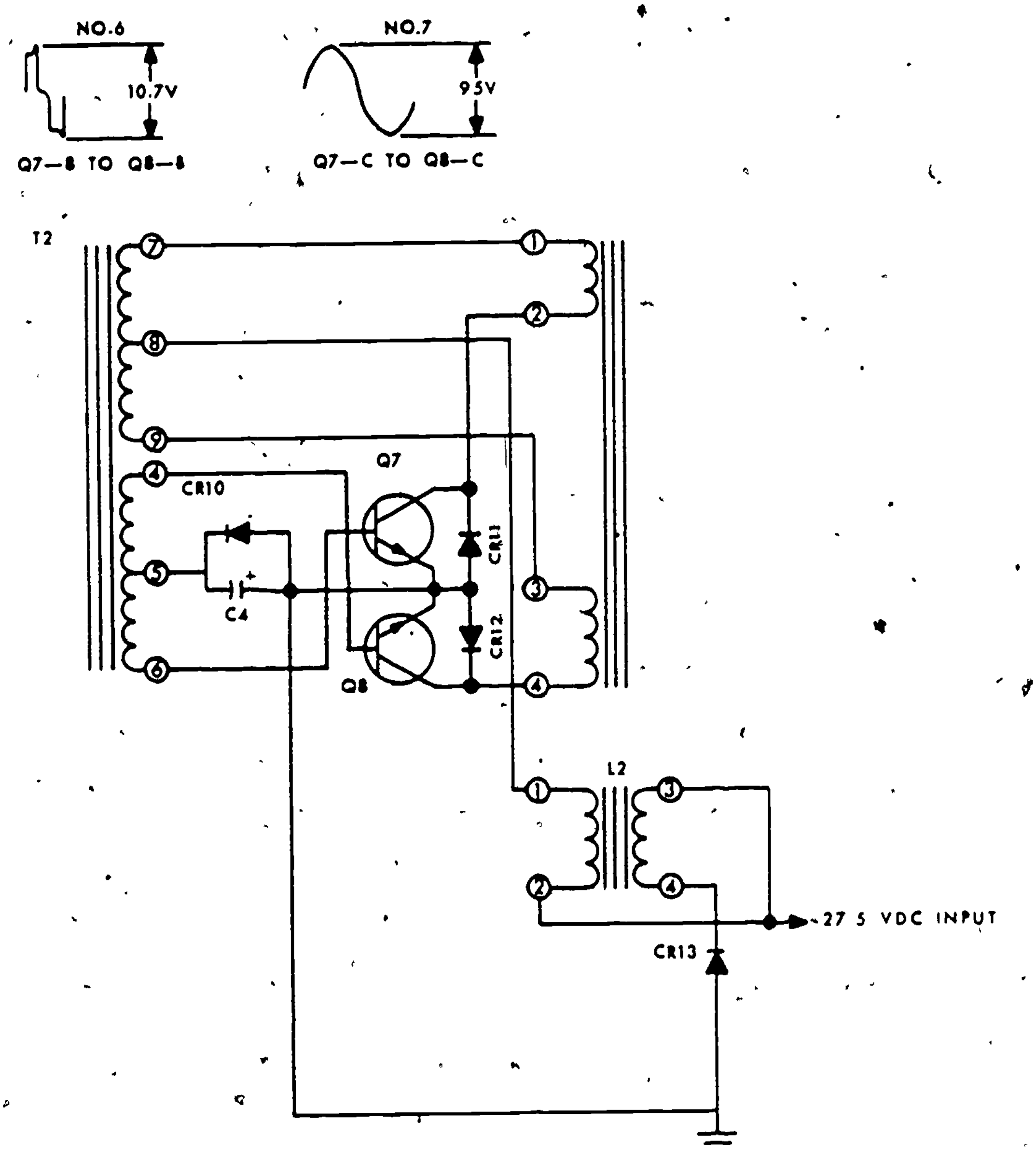

Figure 86. Push-pull output circuit.

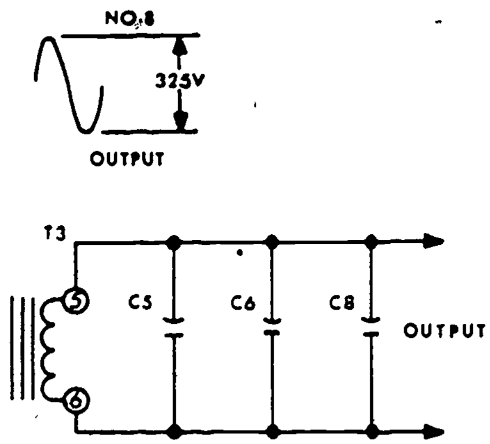

Figure 87. Resonant output tank circuit.

the output signal will be reduced proportionally and then coupled to the push-pull output circuit through pulse transformer T2.

25-19. **Push-Pull Output Circuit.** The push-pull output circuit, consists of transformers T2 and T3, transistors Q7 and Q8, and reactor L2 (see fig. 86). This circuit develops a sinusoidal output signal whose magnitude is dependent upon the width of the input pulses. The input signal (see waveform 6) is applied to the bases of transistors Q7 and Q8, which make up a class "B" push-pull amplifier. This signal is then amplified but, due to the reactances offered by the coils of transformers T2 and T3 and reactor L2 to the square pulse, a sinusoidal output signal is produced (see waveform 7). Since current through this total reactance increases exponentially as a function of time, an increase in the input pulse width will increase the period for current flow. This allows the current through each transistor to rise to greater values with a corresponding increase in the output voltage.

25-20. We have shown that, as the inverter output voltage increases, the width of the input pulse to the push-pull output circuit decreases. Therefore, its output voltage decreases. If, however, the inverter output voltage decreases, then by the same reasoning the output from the push-pull output circuit increases. Obviously there should be some operating point where the entire circuit is stablized. This point is established by the value of the resistance selected for resistor R14 in the voltage sensing circuit. The regulated output from the push-pull output circuit is coupled to the resonant output tank circuit through transformer T3.

25-21. **Resonant Output Tank Circuit.** A secondary of transformer T3 and capacitors C5, C6, and C8 comprise the resonant output tank circuit (see fig. 87). This circuit, which is a series-resonant circuit, is tuned for 400 Hz. Therefore, when the frequency of the input voltage is 400 Hz the current through the tank circuit will be a maximum. Since the resistance of this circuit is low compared to the capacitive reactance, the Q will be high. However, the voltage across the capacitors is equal to Q $\times$ E (applied). Therefore, the output voltage across the capacitors will be greater than the voltage induced into the secondary winding of transformer T3. This output voltage is the inverter output. Under rated loads it will be approximately 325 volts ac peak to peak (115 volts RMS) oscillating sinusoidally at 400 Hz.

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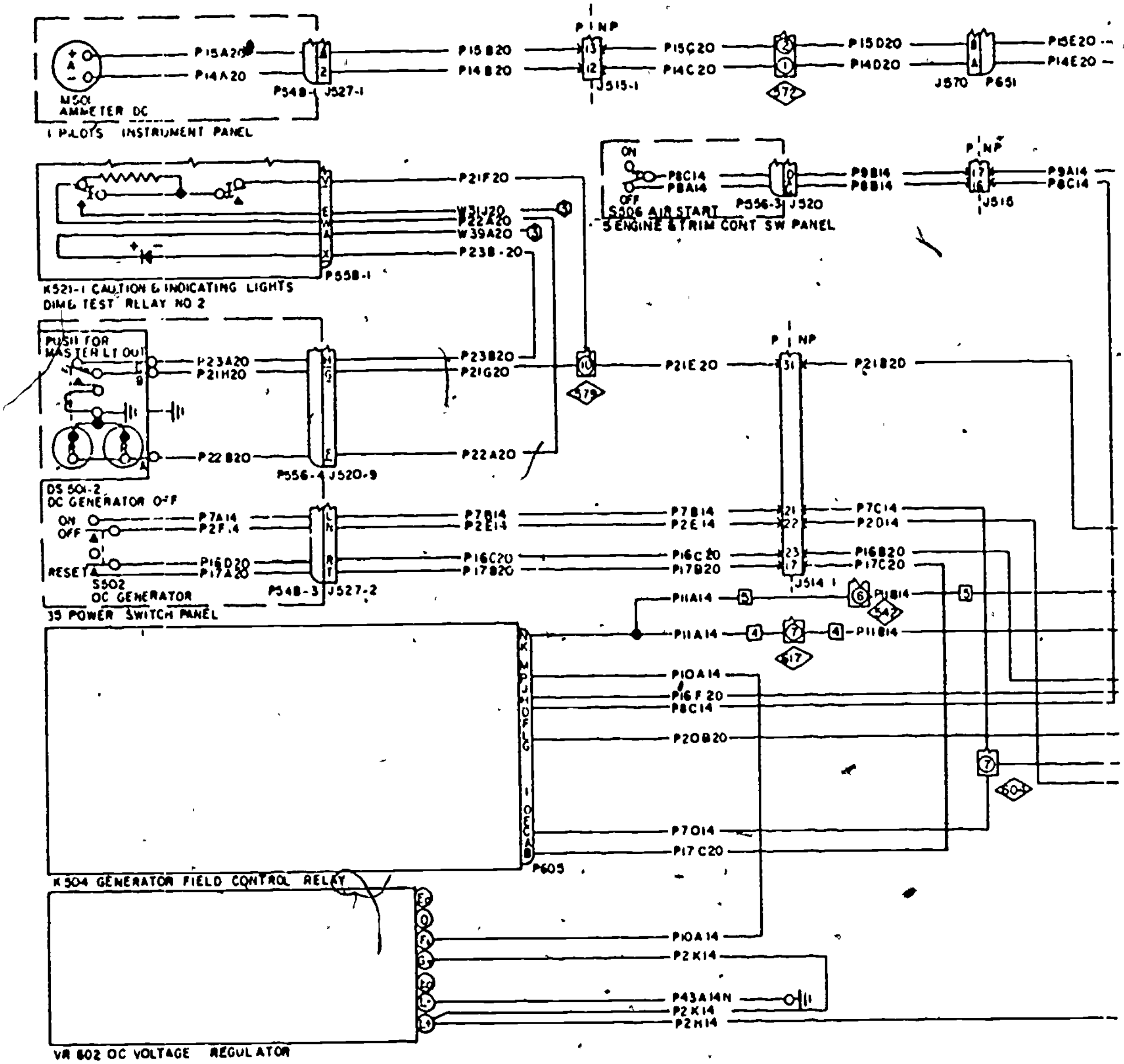

380

Foldout 1.

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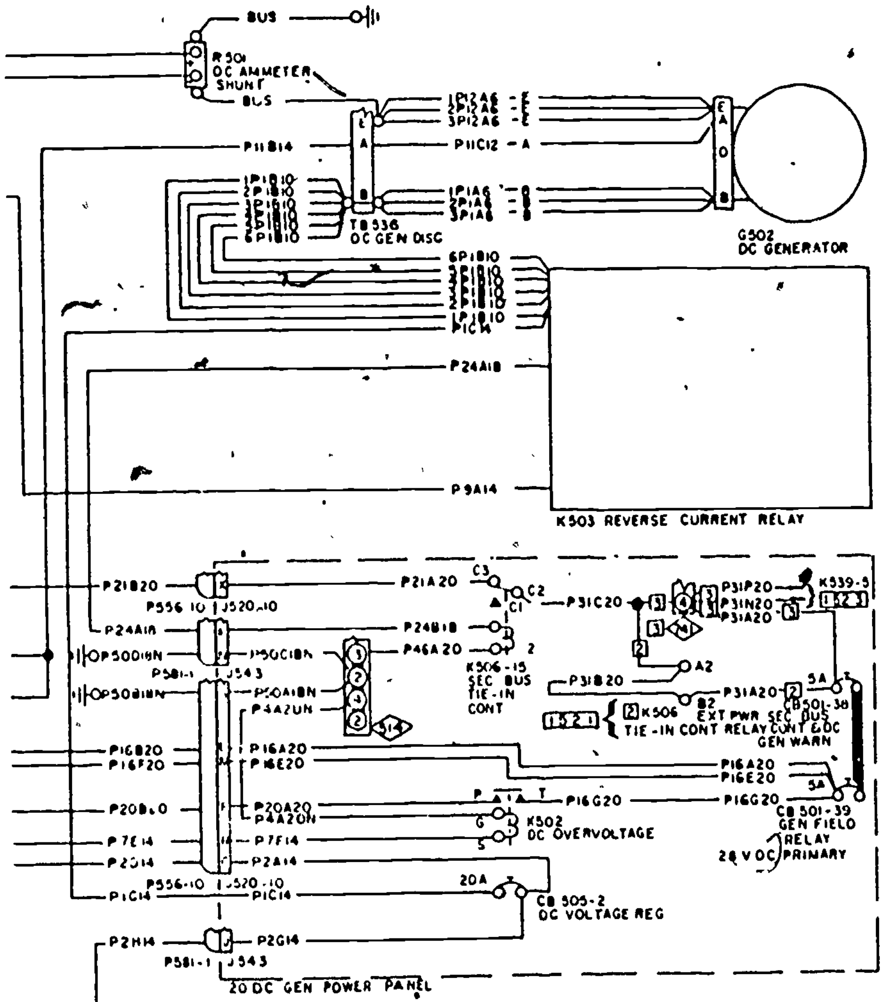


CSC 7409

REFERENCE ITEM LIST			
ITEM NO	NOMENCLATURE	PART NO.	STATION NO
PANEL 2	PILOT'S INSTRUMENT		126
PANEL 5	ENG & TRIM CONT SW		133 LH
PANEL 20	DC GEN POWER		140 LH
PANEL 11	POWER SWITCH		120 RH
CB104 16	SECONDARY BUS CONTROL & DC GEN WARN	MS25361 5	PANEL 20
CB104 35	GEN FIELD RELAY	MS25361 5	PANEL 20
CB105 2	DC VOLTAGE REGULATOR	MS25361 20	PANEL 20
[illegible]	LIGHT ASSY DC GEN OFF		PANEL 11
G502	GENERATOR, DC		115 LH
J516-1	RECP		150 RH
J511	RECP		100 LH
J515 1	RECP		151 RH
J520	RECP (P556 10	AN3102A 20 21S	PANEL 5
J520-5	RECP (P556 5)	AN3102A 20 21S	PANEL 11
J520-10	RECP (P556 10)	AN3102A-20 21S	PANEL 20
J521 1	RECP (P560 2)	AN3102A-20 21SX	PANEL 1
J527 8	RECP (P560 3)	AN3102A 20 21SX	PANEL 35
J543	RECP (P581 1)	AN3102A 20 19S	PANEL 20
J576	RECP (P633)	AN3102A-24-7S	312 LH
K502	RELAY OVER VOLTAGE		PANEL 20
K503	RELAY REVERSE CURRENT	AN3025-1	122 5 LH
K504	RELAY GEN FIELD CONT		115 LH
K506	RELAY EXTERNAL POWER TIE IN CON		PANEL 20
K506-15	RELAY SEC BUS TIE IN CON		PANEL 35
K533-1	RELAY, CAUTION & IND. LT. DIM & TEST NO 2		127 RH
M501	AMMETER DC		PANEL 1
P560 1	PLUG (J527 3)	[illegible]-20 21PX	PANEL 1
P560 5	PLUG (J521 2)	[illegible] 20 21PX	PANEL 35
P556 1	PLUG (J520)	[illegible] 20 21P	PANEL 5
P556 5	PLUG (J520 5)	[illegible]-20 21P	PANEL 11
P556 10	PLUG (J520 10)	[illegible] 20 21P	PANEL 20
P510 1	PLUG CAUTION DIM & TEST RELAY NO 2	[illegible] 16 10S	127 RH
P581 1	PLUG (J543)	[illegible]-20 19P	PANEL 20
P605	PLUG GEN FIELD CONT RELAY	[illegible] 08 3S	115 LH
P633	PLUG (J576)	AN3106B 24 7P	312 LH
R501	SHUNT DC AMMETER		112 5 LH
S502	SWITCH DC GEN	AN3022 8	PANEL 11
S506	SWITCH, AIRSTART	AN3023 2	PANEL 5
TB535	TERM BD	AN3036-1 5	PANEL 20
TB536	TERMINAL BOARD	AN3036 1 5	PANEL 20

REFERENCE ITEM LIST			
ITEM NO	NOMENCLATURE	PART NO	STATION NO
TB536	TERM BD		[illegible]
TB532	TERM BD	AN3410 1 20	132 LH
TB575	TERM BD	AN3410 1 10	123 RH
TB600	TERM BD	AN3410 11	205 LH
TB657	TERM BD	AN3410 1-10	222 5 RH
VR502	REGULATOR DC VOLTAGE		310 LH

	[illegible]	[illegible]	PART OF
5	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]
4	[illegible]	[illegible]	[illegible]
	[illegible]	ONLY	PART OF
	[illegible]	ONLY	PART OF
3	[illegible]	ONLY	PART OF
	[illegible]	ONLY	PART OF
	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]
2	[illegible]	ONLY	PART OF
	[illegible]	ONLY	PART OF
1	[illegible]	[illegible]	[illegible]
	SN°	THRU	[illegible]
EFFECTIVE ON			

[illegible]

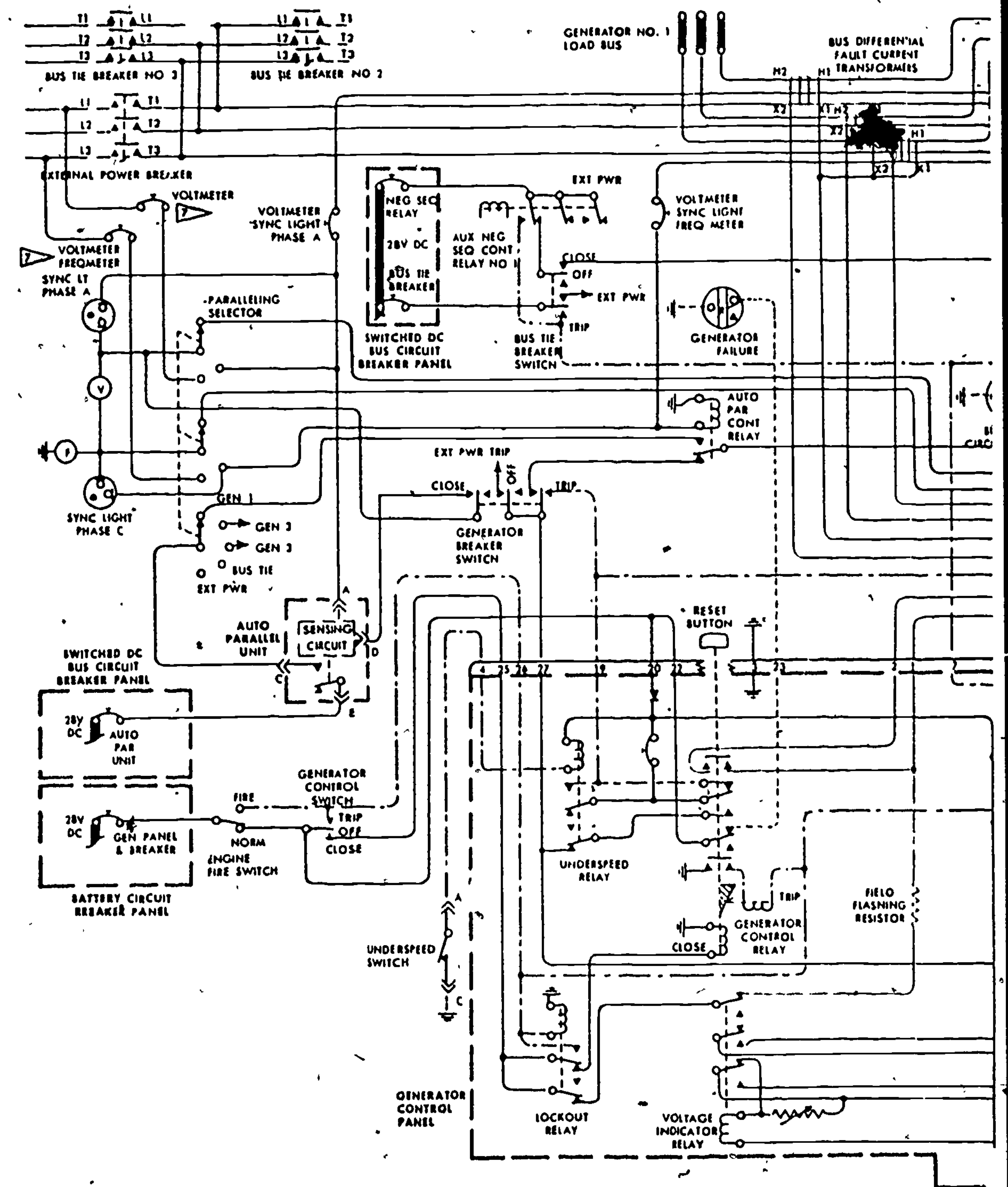
NOTES

1. [1 5 2 1] BUS TIE IN SYSTEM
2. SEE APPLICABLE EFFECTIVITY OF SYSTEMS LISTED ABOVE
3. UNDERLINED LETTERS DENOTE LOWER CASE
4. FOR DIM & TEST CIRCUIT SEE CAUTION, WARNING & INDICATOR LIGHT TEST SYSTEM
5. FOR COMMON CONNECTIONS SEE FUEL SUPPLY SYSTEM - BOOSTER PUMPS
6. MS 3106 PLUGS MAY BE USED WHERE BUAER 56A1453 PLUGS ARE SPECIFIED

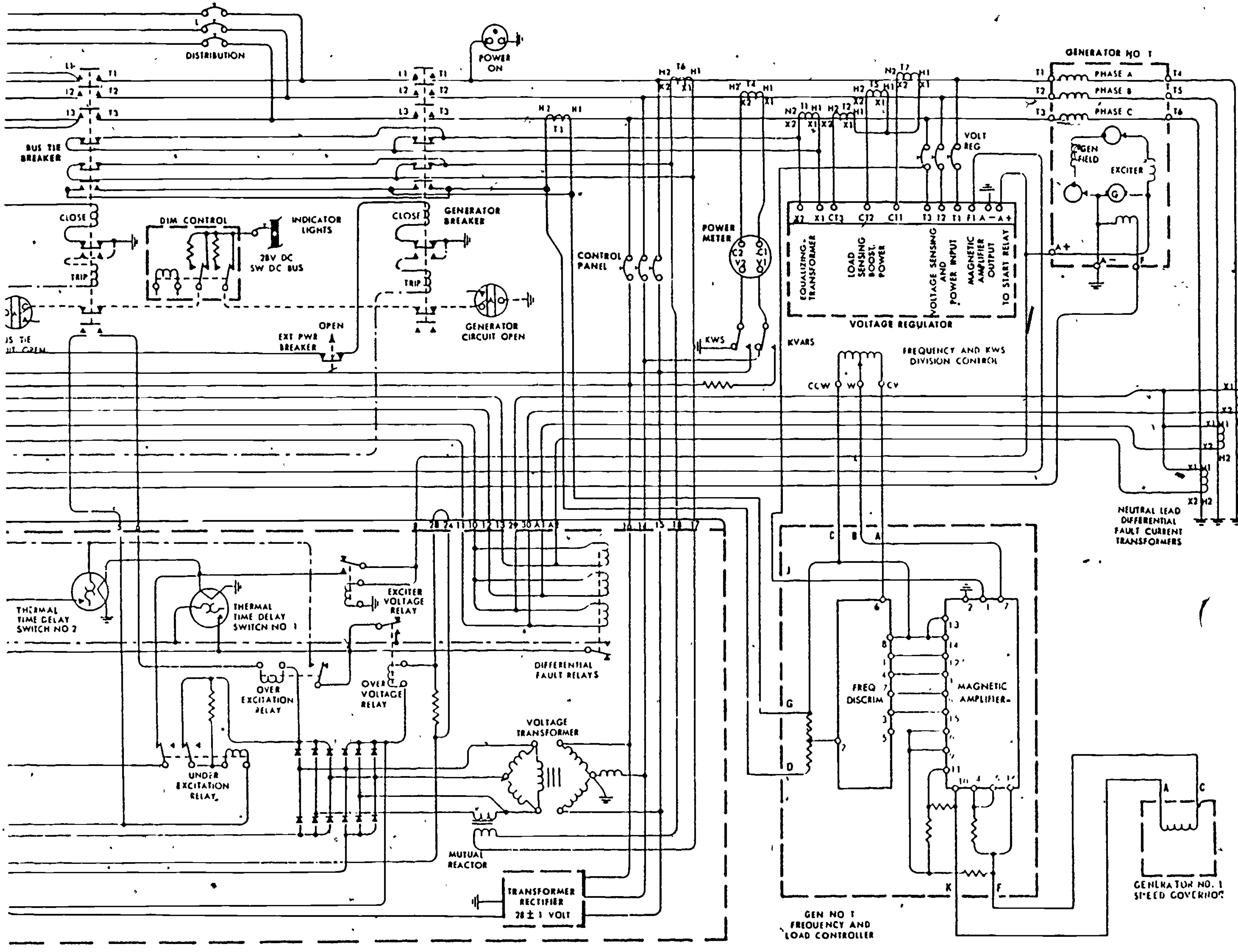
AIRPLANE MODEL	TITLE	EFFECTIVE ON
F-100D	D. C. GENERATOR SYSTEM	AF56 2[illegible] THRU AF56 [illegible]; AF56 [illegible] THRU AF56 [illegible]; 1P27 CHANGE LETTER B

Foldout 1. Part I Typical wiring diagram.

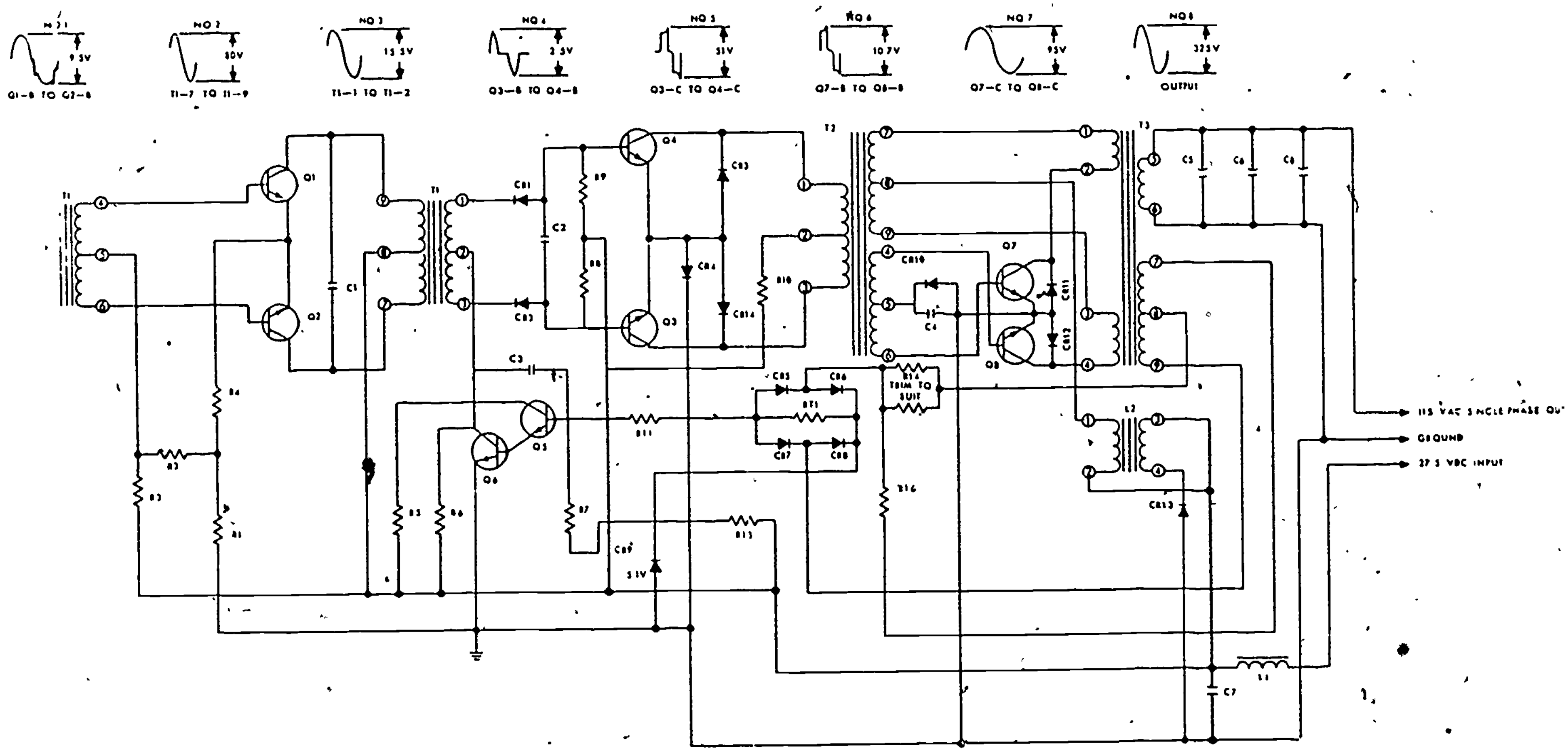
Part II Reference item list.



Foldout 2. Multiengine generator system



Foldout 2. Multiengine generator system.



Foldout 3. Static power inverter, schematic diagram

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WORKBOOK

AIRCRAFT ELECTRICAL REPAIRMAN

This workbook places the materials you need *where* you need them while you are studying. In it, you will find the Study Reference Guide, the Chapter Review Exercises and their answers, and the Volume Review Exercise. You can easily compare textual references with chapter exercise items without flipping pages back and forth in your text. You will not misplace any one of these essential study materials. You will have a single reference pamphlet in the proper sequence for learning.

These devices in your workbook are autoinstructional aids. They take the place of the teacher who would be directing your progress if you were in a classroom. The workbook puts these self-teachers into one booklet. If you will follow the study plan given in "Your Key to Career Development," which is in your course packet, you will be leading yourself by easily learned steps to mastery of your text.

If you have any questions which you cannot answer by referring to "Your Key to Career Development" or your course material, use ECI Form 17, "Student Request for Assistance," identify yourself and your inquiry fully and send it to ECI.

Keep the rest of this workbook in your files. Do not return any other part of it to ECI.

EXTENSION COURSE INSTITUTE

Air University

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STUDY REFERENCE GUIDE

1. *Use this Guide as a Study Aid.* It emphasizes all important study areas of this volume.

2. *Use the Guide as you complete the Volume Review Exercise and for Review after Feedback on the Results.* After each item number on your VRE is a three digit number in parenthesis. That number corresponds to the Guide Number in this Study Reference Guide which shows you where the answer to that VRE item can be found in the text. When answering the items in your VRE, refer to the areas in the text indicated by these Guide Numbers. The VRE results will be sent to you on a postcard which will list the *actual VRE items you missed.* Go to your VRE booklet and locate the Guide Number for each item missed. List these Guide Numbers. Then go back to your textbook and carefully review the areas covered by these Guide Numbers. Review the entire VRE again before you take the closed-book Course Examination.

3. *Use the Guide for Follow-up after you complete the Course Examination.* The CE results will be sent to you on a postcard, which will indicate "Satisfactory" or "Unsatisfactory" completion. The card will list *Guide Numbers* relating to the questions missed. Locate these numbers in the Guide and draw a line under the Guide Number, topic, and reference. Review these areas to insure your mastery of the course.

Guide Number	*Guide Numbers 200 through 235*
200	Introduction to Aircraft Batteries and Servicing Equipment; Lead-Acid Batteries: General; Safety; Shop Operation, pages 1-6
201	Lead-Acid Batteries: Battery Charging Methods; Capacity Testing; Maintenance, pages 6-10
202	Nickel-Cadmium Batteries, pages 10-15
203	Silver-Zinc Batteries, pages 15-18
204	Introduction to Power Systems Test Equipment; DC Test Equipment, pages 19-22
205	AC Test Equipment, pages 22-28
206	The T-170 Tester, pages 28-33
207	The MC-2 Test Stand, pages 33-35
208	The A-1 Load Bank Tester, pages 35-38
209	L-1A Inverter Stand; Component Testing, pages 38-39
210	Introduction to DC Generator Systems; DC Generator: General; Simple Generator; Generator Types and Field Distortion, pages 40-42
Guide Number	
211	DC Generator: General Maintenance Requirements, pages 42-47
212	DC Generator System Components, pages 47-52
213	DC Generator System Operation, pages 52-56
214	DC Generator System Troubleshooting: General; Generator Lead Identification, Generator Trouble Indications, pages 56-58
215	DC Generator System Troubleshooting: Troubleshooting by Use of a Voltmeter and by Use of an Ohmmeter, pages 58-61
216	DC Generator System Troubleshooting: Schematics and Wiring Diagrams, pages 61-63
217	Introduction to Transformer-Rectifier Systems; Transformer-Rectifiers, pages 64-67
218	Transformer-Rectifier Testing, pages 67-69
219	T-R Power System and Maintenance, pages 69-70

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Guide Number	
220	Introduction to AC Generator Systems; AC Generators: General; Generator Frequency; Generator Load Frequencies; Paralleling Requirements, Generator Rating, pages 71-74
221	AC Generators: Variable-Frequency Generators, pages 74-76
222	AC Generators: Constant-Frequency Generators; Maintenance Requirements, pages 76-80
223	AC Generator Drive, pages 80-84
224	AC Generator Control System Components: General; Frequency and Load Controller; Automatic Paralleling Unit, pages 84-87
225	AC Generator Control System Components: Mag-Amp Voltage Regulator; Regulator Operation; Regulator Control, pages 87-90
226	AC Generator Control System Components: Amplifier Stages; Generator Control Panel, pages 90-92

Guide Number	
227	Ac Generator System Operation and Troubleshooting: General; AC Generator System Operation, pages 92-95
228	AC Generator System Operation and Troubleshooting: External Power System, pages 95-98
229	AC Generator System Operation and Troubleshooting: Generator System Troubleshooting; Steps in Becoming a Master Electrician; Typical Problem; Trouble Analysis, pages 98-101
230	Introduction to Motors and Inverters; DC Motors, pages 102-106
231	AC Motors: General; Universal Motors; Induction Motors, pages 106-109
232	AC Motors: Single-Phased Motors, pages 109-111
233	AC Motors: Two-Phase Motors; Three-Phase Motors; Synchronous Motors, pages 111-113
234	Rotary Inverters, pages 113-117
235	Static Inverters, pages 117-123

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CHAPTER REVIEW EXERCISES

The following exercises are study aids. Write your answers in pencil in the space provided after each exercise. Immediately after completing each set of exercises, check your responses against the answers for that set. Do not submit your answers to ECI for grading.

CHAPTER 1

Objectives. To gain the knowledge needed to solve problems requiring the inspection and servicing of lead-acid and alkaline batteries. To be able to explain correct procedures for performing the required inspection and servicing on these batteries and also to explain the proper procedures and safety precautions to be observed in the maintenance of batteries, servicing, and charging equipment.

1. When handling or mixing electrolyte, what safety precautions should be observed? (1-6)

2. Why should a deluge shower and eye wash be installed in a battery shop? (1-6, 7)

3. What gas is produced when charging batteries? What hazards does it create? (1-8)

4. What is the open circuit voltage of a lead-acid cell? (1-10)

5. Explain the term "specific gravity." (1-13)

6. What is the proper way to mix electrolyte used in lead-acid batteries? (1-15)

7. What should be the specific gravity of a fully charged lead-acid cell? (1-17)

8. When should a hydrometer test be taken of a lead-acid cell? (1-19)

9. What is used to neutralize spilled battery acid? (1-22)

10. How is the correct level of electrolyte established in a lead-acid cell? (1-24)

11. What is the constant-current charging method? (1-27)

12. What determines the charging current in a string of batteries connected in series? (1-31)

13. What is the constant-potential method of charging batteries? (1-34)

14. What can cause the apparent rapid boiling of the electrolyte while charging batteries? (1-37)

15. What is the purpose of capacity testing a lead-acid battery? (1-42)

16. How is a lead-acid battery charged prior to performing a capacity test? (1-42)

17. What happens to a lead-acid battery that fails the capacity test? (1-45)

18. What is used to neutralize the electrolyte used in nickel-cadmium batteries? (2-4)

19. Why are lead-acid batteries isolated from alkaline batteries? (2-7)

20. What is the proper electrolyte level in nickel-cadmium batteries? (2-10)

21. How is the state of charge of nickel-cadmium batteries determined? (2-12)

22. What methods can be used to charge nickel-cadmium batteries? (2-15)

23. What are the three functions of the charger/analyzer? (2-19)

24. What is the lead-acid battery test that serves the same function as the discharger section in the charger/analyzer? (2-21)

25. What wrench is necessary to perform work on nickel-cadmium batteries? (2-23)

26. What is the procedure for the installation of a new cell in a nickel-cadmium battery? (2-25)

27. What is the electrolyte solution used in alkaline batteries? (2-9, 3-4)

28. How is the electrolyte level determined in the silver-zinc battery? (3-7)

29. What does the term "soaking period" mean as applied to a silver-zinc battery? (3-8)

30. How is the state of charge of a silver-zinc battery determined? (3-10)

31. What is formation charging? (3-13)

32. What is the recommended method of charging silver-zinc batteries? (3-17)

CHAPTER 2

Objective: To acquire a working knowledge and understanding of aircraft power systems test equipment.

1. What is the purpose of the load bank on the A-2 generator test stand? (4-4)

2. What is the purpose of the 0- to 10-amp rheostat located on the panel of the dc generator test stand? (4-10)

3. Why must the A-2 generator test stand be modified? (4-15)

4. Who is responsible for maintaining the A-2 generator test stand? (4-17)

5. What is the function of the T-31 dc test set? (4-20)

6. Why is it possible to bench check a generator control panel without access to the internal components? (4-20)

7. What maintenance can be performed on the T-31 test set by shop personnel? (4-22)

8. What is the purpose of the T-35 tester? (5-2)

9. What is the purpose of the ac electronic generator in the T-35 tester? (5-4)

10. What is the purpose of the power amplifier in the T-35 tester? (5-5)

11. What power is required to operate the T-35 tester? (5-10)

12. What is the purpose of the feedback circuit used in the power amplifier? (5-14)

13 In the dc power supply metering and control unit how is relay contact operation indicated? (5-17)

14. Of the two testers. T-35 and T-170, which one is capable of handling a greater load? (6-3)

15. What are the component parts of the T-170 tester? (6-4)

16. What is the purpose of the fixed 400 and 1600Hz output of the T-170 test set? (6-5)

17. What is the programmer and relay control center used for on T-170 test set? (6-9)

18. How is the operation of the control dc power supplies controlled? (6-13)

19. What components make up the digital instrumentation system of the T-170 test set? (6-15)

20. The power amplifying section of the power amplifiers is a push pull configuration using two power triode tubes. When the power output demands of the tubes are above 60 watts, in what class are the tubes operated? (6-24)

21. How is the T-170 test set programmed? (6-27, 28)

22. What is the purpose of the recorder unit used by the T-170 tester? (6-32)

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23. What is the purpose of the MC-2 test stand? (7-1)

24. How is the start prime mover disengaged when the main prime mover is started? (7-3)

25. What is the purpose of the limit switches used with both the start and main prime mover? (7-5)

26. If the hydraulic oil in the reservoir becomes too hot, what will happen to the MC-2 test stand? (7-6)

27 What is the purpose of adapter kits used with the MC-2 test stand? (7-8)

28 What is the function of the A-1 load bank tester? (8-1)

29. What is the source of power for operating the A-1 load bank? (8-2)

30. What is the total reactive load the A-1 load bank can provide? (8-3)

31. What is the total resistive load provided by the A-1 load bank? (8-4)

32. How are the ammeter and wattmeter on the A-1 load bank protected from overload? (8-6, 8-7)

33. What is the purpose of the thermostat switch on the A-1 load bank? (8-10)

34. What are the basic requirements for testing an inverter? (9-2)

35. What are the power requirements for the L-1A inverter tester? (9-3)

36. To obtain voltage and current reading while testing a single phase inverter, what position should the volts/amps switch be in? (9-5)

37. What is the greatest single factor to consider when a system malfunction is reported? (10-2)

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38. What determines the test requirement of any system component? (10-3)

CHAPTER 3

Objective. To gain a background knowledge of the operation, troubleshooting, testing, repair, inspection, and maintenance of an aircraft single and multigenerator dc power system.

1. What is a generator? (11-1)

2. If you have a magnetic field and a conductor, what else is needed to induce a voltage in the conductor? (11-2)

3. What component in the generator contains the secondary circuit? (11-4)

4. What component of the generator transforms the generated ac into dc? (11-4)

5. What is a self-excited generator? (11-6)

6. Name the types of generators when they are classified according to the relationship of the armature to the field windings. (11-7)

7. What prevents the use of the series-wound generator on aircraft? (11-8)

8. What type generator has its field coils connected in parallel with the armature? (11-9)

9. In a compound-wound generator what is the relationship of the field coils to the load? (11-11)

10. What is armature reactance? (11-13)

11. What are the four ways of taking care of the emf of self-induction and armature reaction? (11-14-17)

12. How are the interpole windings connected in relation to the armature? (11-14)

13. What is the action of the slotted pole pieces? (11-15)

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14. What is the action of the laminated pole tips? (11-16)

15. How are the compensating windings connected in relation to the generator armature? (11-17)

16. What color is a normally operating commutator? (11-22)

17. What are the effects of incorrect brush spring pressure? (11-23)

18 What is the minimum contact surface on a properly seated brush? (11-27)

19. What is most commonly used for seating generator brushes? (11-29)

20. What is the indication of a grounded armature? (11-30)

21. In the growler test, what does a buzzing hacksaw blade indicate? (11-33)

22. When making a generator field test, what indicates a grounded circuit? (11-35)

23. What indication does an open armature give in the growler test? (11-36)

24. What is the purpose of the voltage regulator? (12-4)

25. What is the most common method used to control the current in the field coils? (12-4)

26. What happens to current flow through the field coils if carbon stack resistance is lowered? (12-7)

27. What is the effective range for which the carbon-pile voltage regulators can be adjusted? (12-11)

28. What is the purpose of the stabilizing resistor circuit? (12-13)

29. Why must a regulator be allowed to warm up before it is adjusted? (12-15)

30. Why is the RCR referred to as a differential relay? (12-19)

31. What are some of the functions of the RCR? (12-19)

32. What other unit operates simultaneously with the overvoltage relay? (12-23)

33. Name the two relays that are inside the field control relay. (12-24)

34. Name the essential units in a single-generator control system. (13-4)

35. What is the purpose of initial power on the generator system? (13-7)

36. What controls the current flow in the field circuit? (13-10)

37. How may the M-2 field control relay be reset? (13-11)

38. What approximate voltage will cause the overvoltage relay to close? (13-12)

39. What is responsible for the operation of the equalizer circuit? (13-16)

40. If two generators are not dividing the load properly, what would you do first? (13-19)

41. What should be the first check of the generator system if the cockpit voltmeter read zero volts? (14-9)

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42. What would be the cockpit voltmeter reading if the "B" finger of the regulator base were not making contact with the "B" prong of the voltage regulator? (14-10)

Directions (Exercises 43-52.): The voltmeter readings in CRE table 1 were taken from the circuit shown in figure 44 with the regulator installed and the engine running at cruising speed. The ohmmeter readings were taken with the engine stopped and the regulator removed and the generator switch in the OFF position. Determine the nature and location of the trouble as accurately as possible. (14-28)

Exercise	Cockpit Voltmeter (volts)	"B" to Gnd	"A" to Gnd	"A" to "B"	"A" to "B" on the generator (leads removed)	Ref
43	2	.5	infinity	infinity	3.5	14-28
44	2	.5	infinity	infinity	infinity	14-28
45	2	infinity	3	infinity	3.5	14-28
46	8	.5	30	30.5	3.5	14-28
47	0	0	3	3	3.5	14-28
48	1	.5	0	.5	.5	14-28
49	0	infinity	3	infinity	3 5	14-28
50	0	infinity	infinity	3.5	3.5	14-28
51	0	.5	3	3.5	3.5	14-28
52	30+	.5	.5	0	0	14-28

CRE Table 1

TROUBLESHOOTING INFORMATION OHMMETER READINGS AT REGULATOR BASE

CHAPTER 4

Objective: To gain the knowledge required to identify and explain the steps and procedures in the operation, troubleshooting, and maintenance of transformer rectifier power systems. This includes the special T-R units used in aircraft battery charging systems.

1. What is the difference between a 50-ampere output rectifier type T-R unit and one rated at 100 amperes? (15-3)

2. Why is the four operations of a T-R unit critical? (15-4)

3. How is the static T-R unit cooled? (15-7)

4. In the battery charging T-R unit, what happens to the output voltage when the load is increased? (15-9)

5. What are the minimum and maximum output voltages for the static T-R unit? (16-5)

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6. What should the output voltage of the battery charging T-R unit be when it is connected to a 10-ampere load? (CRE Table 2)

Load (Amperes)	Output Voltage (D-C)
0	27.8 to 28.8
4	28.9 to 29.7
10	28.2 to 30.9
25	26.5 to 29.8

CRE Table 2

BATTERY CHARGER T-R TEST VOLTAGES

7. Using figure 49, is it possible for the bus tie relay to become energized if current limiter Nr. 1 remains intact? (17-2-6; Fig. 49)

8. According to figure 49, when does the bus tie relay become energized? (17-2-6; Fig. 49)

9. What two conditions must be met before battery power can be applied to an essential bus? (17-2-6; Fig. 50)

CHAPTER 5

Objective. To demonstrate a knowledge of aircraft ac power systems and how they operate, and show an ability to analyze system malfunctions.

1. What is the frequency of a generator output when the rotor has 6 poles and is turning at 380 rpm? (18-5)

2. What types of loads are connected to a constant-frequency generator? (18-8)

3. What effect does real load (kw) have on the generator rotor? (18-13)

4. What determines the generator's ability to carry reactive load? (18-15)

5. What type of ac generator can be operated in parallel? (18-19)

6. What conditions must be satisfied before generators can be operated in parallel? (18-19)

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7. Why are generators operated in parallel? (18-19)

8. How are ac generators rated? (18-24)

9. What is the purpose of the "squirrel cage" winding in the starter of a variable-frequency ac generator? (18-27)

10. What type of load can be connected to a variable-frequency generator? (18-34)

11. What are the two different types of ac generators in general use in the Air Force? (18-38)

12. What is the purpose of the permanent magnet generator? (18-34)

13. How are brushless generators cooled? (18-46)

14. How is the speed of a constant-frequency generator controlled? (18-56)

15. When is a drive considered to be in an underdriven condition? (19-7)

16. In what condition is the drive when the pump wobbler assumes a positive angle? A negative angle? (19-7, 8)

17. When is a drive considered to be in an overdrive condition? (19-8)

18. When is a drive considered to be in a straight-through condition? (19-9)

19. What are the functions of the drive governor system? (19-11)

20. What is the basic generator frequency established by the "basic speed governor" of a 40 kva CSD? (19-14)

413

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21. What two means are provided to adjust a basic speed governor to maintain the generator frequency at 400 Hz? (19-15 and 16)

22. What are the functions of a limit governor? (19-18)

23. What is the purpose of the over-running clutch? (19-22)

24. What is the key component in controlling kw load division? (20-3)

25. What is the purpose of the frequency-and-load controller during isolated generator operation? During parallel operation? (20-3, 4)

26. How is the amount of load on a generator sensed? (20-4)

27. On the CSD, where are the frequency-control signals applied? (20-4)

28. What is the purpose of the frequency-discriminator circuit in the 40-kva frequency-and-load controller? (20-7)

29. On what principle does a magnetic-amplifier voltage regulator operate? (20-12)

30. What is meant by the term "generator error?" (20-13)

31. What is the main purpose of the second-stage output of the magnetic amplifier? (20-14)

32. Why is a feedback circuit used in the first stage of a magnetic amplifier voltage regulator? (20-15)

33. What is the key component in controlling kvar load division? (20-19)

34. What will result if the boost current transformer (used with the magnetic amplifier voltage regulator) connected to the voltage regulator were reversed? (20-25)

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35. What unit is used to open and close the exciter field of a generator? (20-34)

36. What component is used to prevent generator cycling during a fault condition? (20-36)

37. What system component detects generator undervoltage during parallel operation? (20-40)

38. What circuit is used to protect against excessive reactive current flow in the generators or reactive unbalance in the distribution system? (20-40)

39. Under what conditions does the OE-UE loop circuit function? (20-42)

40. What is the purpose of a bus tie breaker? (21-5)

41 When the generator control relay closes, what circuit functions take place? (21-7)

42. In a CSC-driven generator system how is the generator breaker closed? (21-8)

43. During manual paralleling of the generator how are the bus tie and generator breakers positioned? (21-10)

44. At engine shutdown how is the generator breaker opened? (21-13)

45. The main external power receptacle discussed in the text provides for what two components? (21-20)

46. When is the main external power lockout relay energized? (21-24)

47. What relay in the external power system will prevent ac power with the wrong phase sequence being connected to the aircraft bus? (21-27)

48. How is the disarm relay circuit completed during load bank operation? (21-31)

49. List the logical steps required to identify and remedy system malfunctions. (21-36)

50. How do you identify a problem? (21-39)

51. Why is it helpful to write down the possible causes of a malfunction when troubleshooting? (21-40)

52. When repairing an electrical system, before you make a costly replacement, how can you prove your conclusions are correct? (21-44)

53. What are the most common causes of frequency troubles? (21-51)

54. What are the voltage output indications of an ac generator if the generator drive is locked in underdrive? (21-54)

55. What voltage indication will be caused by exciter-generator brushes worn beyond acceptable limits? (21-54)

56. What will cause low bus voltage when two or more generators are operating in parallel? (21-55)

57. What would cause the output of a generator controlled by a magnetic amplifier regulator to cycle between 100 and 200 volts? (21-55)

58. What is the most probable cause of high generator voltage output? (21-56)

CHAPTER 6

Objective: To gain a knowledge and understanding of aircraft dc and ac motors and rotary and static inverters.

1. What is motor action? (22-3, 4)

2. What are the factors that control torque? (22-5)

3. Explain the presence of CEMF in a dc motor. (22-6-8)

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4. Explain the internal connections in a series motor. (22-10)

5. Which type motor has the best speed control? (22-14)

6. Why would a cummulative compound be a good motor to drive the ac generator section of an inverter? (22-15-17)

7. What is the one factor that must be considered in the design of a continuous duty motor that limits the intermittent duty motor to short runs? (22-18)

8. The shunt section of a cummulative compound motor is controlling the speed of the shaft. If a variable resistor is placed in series with the shunt field, what are the effects of motor speed if current increases or decreases in the resistor? (22-23, 24)

9. Why is the split field the most easily reversed dc motor? (22-27-29)

10. Into what three classes are induction motors divided? (23-1)

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11. What determines the speed of an induction motor? (23-4)

12. What is the advantage of a wire wound rotor? (23-7)

13. What type of rotor is used in induction motors? (23-5, 8)

14. What is the principle of operation for an induction motor? (23-9)

15. Explain how slip becomes present in an induction motor. (23-11)

16. What is the synchronous speed of an induction motor? (23-12)

17. What auxiliary means may be used to start a single-phase induction motor? (23-16)

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18. How does a capacitor help a single-phase induction motor to be self starting? (23-21)

19. When a starting winding is used only to start the motor, how is it removed from the circuit? (23-23)

20. How is a three-phase induction motor reversed? (23-33)

21. How many phases are necessary for a three-phase motor to run? (23-34)

22. What is synchronous speed and why are synchronous motors constant speed? (23-34, 36)

23. Name the two units that make up a rotary inverter. (24-1)

24 What is the output frequency range for inverters? (24-3)

25. Why do all rotary inverters take dc power from the motor terminals for the excitation of the field instead of using some of the generated voltage and converting it to direct current? (24-14)

26. In an inverter system that has both a main and alternate inverter what component will automatically put the alternate inverter on the load bus if the main inverter fils? (24-23)

27. What are the six basic circuits that make up the static inverter? (25-2)

28. What is the purpose of the oscillator circuit? (25-3)

29. What two signals are applied to the voltage divider circuit? (25-4)

30. What circuit detects a change in the inverter output voltage? (25-8)

31. What circuits combine to form a degenerative feedback circuit? (25-11)

32. What is the prominent characteristic of the output wave shape of the voltage divider circuit? (25-12)

33. How will an increase in the inverter output effect the output signal from the voltage driver circuit? (25-18)

34. How will an increase in the input pulse width effect the magnitude in the output signal from the inverter? (25-19)

ANSWERS FOR CHAPTER REVIEW EXERCISES

CHAPTER 1

1. You should wear goggles or face shield, rubber apron, rubber gloves, rubber boots, and know how to reach fresh water. (1-6)
2. To be used in case electrolyte is accidently splashed or spilled on you. (1-6, 7)
3. Hydrogen gas which is highly flammable and can explode. (1-8)
4. 2.2 volts. (1-10)
5. The comparative weight of a liquid with respect to an equal volume of water. (1-13)
6. The sulphuric acid should always be poured into the water. (1-15)
7. Approximately 1.275. (1-17)
8. Before adding water to the cell. (1-19)
9. Baking soda. (1-22)
10. A small hole is drilled in the stem of a syringe. Then, when the fluid level is lowered to the edge of the hole and the syringe is bottomed on the plates, the level will be correct. (1-24)
11. Current is maintained at a predetermined level throughout the entire period of charge. (1-27)
12. Charging current is determined by the ampere-hour capacity of the smallest capacity battery in the string. (1-31)
13. The voltage is maintained at a predetermined level throughout the entire period of charge. (1-34)
14. Boiling will occur when the battery is overcharged or has been charging at an excessive rate. (1-37)
15. To determine the battery's terminal voltage and state of wear. (1-42)
16. The battery is brought to a full charge and then overcharged for 2 additional hours. (1-42)
17. The battery is either condemned or painted yellow and stenciled for ground use only (1-45)
18. Boric acid. (2-4)
19. Acid will neutralize the alkaline solution which, in turn, will ruin the batteries. (2-7)
20. The electrolyte should be even with the top of the plates. (2-10)
21. State of charge is determined by the amount of current the battery shows when connected to a constant potential charging bus. (2-12)
22. Nickel-cadmium batteries can be charged by the constant-potential method, constant-current method, or by a charged analyzer. (2-15)
23. The charger/analyzer charges, discharges and analyzes batteries. (2-19)
24. Capacity test. (2-21)
25. Torque wrench. (2-23)
26. *a.* Be sure that it is completely discharged.
    b. Coat the sides of the cell with vasoline.
    c. Connect cells with connectors provided.
    d. Torque connecting bolts. (2-25)

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27. The electrolyte is a solution of potassium hydroxide and distilled water. (2-9, 3-4)

28. The cells are filled with a measured amount of electrolyte and do not require additional servicing in their lifetime. (3-7)

29. The battery must stand for 72 hours after servicing. (3-8)

30. The state of charge is determined by measuring the open-circuit voltage of each cell. (3-10)

31. It is a process of charging and discharging silver-zinc batteries in a controlled sequence to condition the battery. (3-13)

32. The constant-current method. (3-17)

CHAPTER 2

1. The load bank is used to provide a load for the generator under test. (4-4)

2. The purpose of the O- to 10-amps rheostate is to control generator output voltage. (4-10)

3. The modified test stand would enable you to test (bench check) all generator system components. (4-15)

4. Electric shop personnel are responsible for maintenance of the A-2 generator test stand. (4-17)

5. The T-31 dc test set provides a fast, uniform method of testing and adjusting dc generator control panels. (4-20)

6. All indications of proper-relay operation are visible on the tester by means of lamps and meters. (4-20)

7. Repair of the T-31 tester is limited to repair of electrical circuit malfunctions. (4-22)

8. To test and adjust ac generator control and protection panels not containing transistors. (5-2)

9. To supply a three-phase and a single-phase low voltage with a manually adjusted frequency (5-4)

10. To amplify the low voltage produced by the ac generator. (5-5)

11. Power required to operate the T-35 tester in 115 volts ac, 60 Hz, single-phase. (5-10)

12. The purpose of the feedback circuit in the power amplifier is to stabilize the gain of the amplifier and reduce distortion in the output-signal. (5-14)

13. Relay contact operation of a unit undergoing test is indicated by lamps. (5-17)

14. The T-170 tester. (6-3)

15. The T-170 test set consists of the following units. ac electronic generator, power amplifiers, amplifier power supplies, power distribution unit, programmer and relay-control center, card switch, voltage-control unit, control dc power supplies, indicator unit, recorder unit, and digital instrumentation system. (6-4)

16. The purpose of the fixed 400 and 1600 Hz output is to simulate ac system with permanent magnet generators (1600 Hz) and making simulated generator paralleling tests (400 Hz). (6-5)

17. The programmer and relay control center provides a means for applying test signals to units undergoing test. (6-9)

18. The control dc power supplies are controlled by the card switch. (6-13)

19. The component parts of the digital instrumentation system are; (1) a five digit electronic counter, and (2) a converter, voltage to frequency. (6-15)

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20. With an output power above 60 watts the tubes are operated in class AB. Below 60 watts then are operated in class A. (6-24)
21. The tester is programmed through the card switch, and programmer and relay control center. (6-27, 28)
22. The recorder unit of the T-170 tester is used to record the outputs of a frequency and load controller under transient test. (6-32)
23. The MC-2 test stand is used to field-testing constant-speed transmissions, their 400 cps ac components and certain ac generators. (7-1)
24. The start prime mover is disengaged automatically by a magnetic clutch when the main prime mover is started. (7-3)
25. The limit switches used on both the start and main prime mover are used to control their high and low speed limits. (7-5)
26. When the hydraulic oil in the reservoir becomes too hot, a temperature controller, on the center panel will shut down the test stand. (7-6)
27. The purpose of the adapter kits is to adapt the test stand to various aircraft systems. (7-8)
28. To apply either resistive loads or reactive loads to 120-208 volt, 400-cps, three-phase ac generator systems under test. (8-1)
29. The entire electrical power required to operate the A-1 load bank is provided by the generator under test and no external source of power is required. (8-2)
30. The A-1 load bank provides a total reactive load of 40 KVAR with a maximum of 13.3 KVAR per phase. (8-3)
31. The A-1 load bank provides a total resistive load of 60 kw with a maximum of 20 kw per phase. (8-4)
32. The ammeter and wattmeter on the A-1 load bank are protected from overload by shorting out their respective circuits. Their range switches must be placed in the maximum range position before their shorting circuits are removed. (8-6, 8-7)
33. To short out the thermostats when the temperature fluctuates and cause the fans to operate continuously (8-10)
34. The basic requirements for testing an inverter are accomplished by measuring the input voltage and current and the output voltage, current, and frequency. (9-2)
35. The L-1A inverter tester requires a 5 kw dc voltage source. (9-3)
36. The volts/amps switch should be in the N position. (9-5)
37. Malfunction in component operation. (10-2)
38. The function or functions that the component is required to perform when installed in a complete system. (10-3)

CHAPTER 3

1. A generator is a machine that changes mechanical energy to electrical energy through electromagnetic induction. (11-1)
2. Relative motion is the third factor needed. (11-2)
3. The armature contains the secondary circuit. (11-4)

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4. The commutator changes ac to dc which is delivered to the generator terminals. (11-4)

5. A self-excited generator is one that provides its own exciting current by the use of residual magnetism. (11-6)

6. Three types of generators according to armature and field relationship are series-wound, shunt-wound, and compound-wound. (11-7)

7. It has a fluctuating voltage output. (11-8)

8. The shunt-wound generator has its field coils connected in parallel with the armature. (11-9)

9. The series field is in series with the load and the shunt field is parallel to the load. (11-11)

10. Armature reactance is the bending and distorting of the normal flux pattern within the generator as a result of the effect of the armature magnetic field on the magnetic field produced by the generator field coils. (11-13)

11. Four means of counteracting field distortion are the use of interpoles, slotted pole pieces, laminated pole tips, and compensating windings. (11-14-17)

12. The interpole windings are connected in series with the armature. (11-14)

13. The slotted pole pieces increase the reluctance of the magnetic circuit for the armature magnetic field. (11-15)

14. The laminated pole tips prevent the concentration of magnetic flux at the pole tips. (11-16)

15. The compensating windings are connected in series with the armature. (11-17)

16. A normally operating commutator is chocolate brown. (11-22)

17. Too much pressure causes excessive brush wear and too little pressure results in jumping brushes, poor output, and the possibility of burning the commutator. (11-23)

18. A properly seated brush will have a minimum of 100 percent contact across the thickness and 70 percent contact across the width of the brush. (11-27)

19. New brushes can be seated by using a strip of Nr. 000 or Nr. 0000 sandpaper the width of the commutator (11-29)

20 The test light will light when connected between the commutator and the armature shaft (11-30)

21. It indicates a short circuit in the armature or the commutator. (11-33)

22. The test lamp will light if there is a grounded circuit. (11-35)

23. No spark when two adjacent commutator segments are shorted together (11-36)

24. The regulator maintains a constant output voltage under varying load conditions (12-4)

25. The most common method is a carbon-pile type regu tor. (12-4)

26. Current flow through the field coils would increase. (12-7)

27. Effective range of regulation is 26 to 30 volts. (12-11)

28. The stabilizing resistor circuit prevents arcing between the discs of the carbon pile. (12-13)

29. Any component should be at its normal operating temperature before adjustments are made (12-15)

30. Because the RCR operates on the difference between generator and bus voltage. (12-19)

31. The reverse-current relay operates as a remotely controlled switch to provide control over the system, and it will automatically open and close the generator output circuit to the bus as the voltage output of the generator varies. (12-21)
32. The M-2 field control relay opens along with the overvoltage relay. (12-23)
33. The trip relay and the reset relay are located in the field control relay. (12-24)
34. The essential units are the RCR, the voltage regulator, the overvoltage relay, and the field control relay. (13-4)
35. Initial power provides trip power in the event of an overvoltage condition, and applies a positive dc potential to the generator field. (13-7)
36. Field current flow is controlled by the carbon stack of the voltage regulator. (13-10)
37. The M-2 field control may be reset by the generator switch or manually by a reset button on the relay itself. (13-11)
38. The overvoltage relay closes at approximately 32.5 volts. (13-12)
39. The equalizer circuit operates if there is a difference in potential between D Terminals. (13-16)
40. First you should lower the voltage of the generator providing the greatest amount of current flow. (13-19)
41. Check the system with another voltmeter to determine if the cockpit voltmeter is correct in its zero reading. (14-9)
42. The cockpit voltmeter would read residual voltage. (14-10)
43. Lead "a" is open. (14-28)
44. The generator field is open. (14-28)
45. There is an open in "b" lead. (14-28)
46. Lead "a" has a loose connection or high resistance. (14-28)
47. Lead "B" or "b" is grounded. (14-28)
48. ~~The field is shorted or grounded inside of the generator.~~ (14-28)
49. There is an open in "B" lead. (14-28)
50. Lead "E" is open. (14-28)
51. Defective switch or voltmeter circuit. (14-28)
52. Leads "A" and "B" are shorted inside of the generator. (14-28)

CHAPTER 4

1. The transformer in the 50-ampere unit has a delta connected secondary, and the 100-ampere unit has a wye-delta connected secondary. (15-3)
2. The T-R unit would fail in a short time without cooling air flowing over the T-R stack. (15-4)
3. It is cooled by convection. (15-7)
4. The output voltage increases. (15-9)
5. Not less than 26 volts nor higher than 31 volts. (16-5)

6. Output should be between 28.2 and 30.9 volts. (CRE Table 2)

7. Yes; If only one T-R starts, the bus tie relay becomes energized through the contacts of the deenergized T-R relay. (17-2-6; Fig. 49)

8. When either of the T-R relays is in the deenergized position and power is available to energize the relay. (17-2-6; Fig. 49)

9. The battery switch must be turned on, and there must be no power present at the T-R bus. (17-2-6; Fig. 50)

CHAPTER 5

1. 19 Hz $f = \dfrac{3 \times 380}{60} = \dfrac{1140}{60} = 19\text{ Hz}.$ (18-5)

2. Reactive (kvar) and real (kw) loads. (18-8)

3. The mechanical lag makes it tend to slow down. (18-13)

4. Voltage regulator. (18-15)

5. Constant-frequency generator. (18-19)

6. Generators must be of the same design; terminal voltages must be equal; frequency must be equal; voltages must be in phase; and phase rotation must be alike. (18-19)

7. To improve the reliability and power capabilities of the system. (18-19)

8. AC generators are rated in kva's at a specified frequency and power factor. (18-24)

9. They provide an even distribution of the field flux. (18-27)

10. Only kw (real loads) can be connected to a variable frequency generator. (18-34)

11. The two types of ac generators in general use are the brush type and the brushless type, either of which may be air cooled or oil cooled. (18-38)

12. It provides excitation for the exciter field, power to operate the generator, and a source of power for the voltage regulator. (18-43)

13. With blast air or engine oil under pressure. (18-46)

14. By a constant-speed drive unit. (18-56)

15. When the input speed to the drive is greater than the required output speed. (19-7)

16. Overdrive. Underdrive. (19-7, 8)

17. When the input speed to the drive is less than the required output speed. (19-8)

18. When the input speed to the drive is the same as the required output speed. (19-9)

19. To control the drive output speed and thereby the generator frequency, and to equalize the load between paralleled generators. (19-11)

20. 395 Hertz per second. (19-14)

21. Mechanically by a precision frequency-control motor geared to the metering piston; and magnetically, by trim coils soldered to the flyweights. In both cases, the signals are furnished by the frequency-and-load controller unit. (19-15, 16)

22. The limit governor places the drive in a full underdrive condition and removes the affected generator from service in case of an underspeed or overspeed condition. (19-18)
23. To prevent an overrunning or motorized generator from damaging the drive. (19-22)
24. The frequency-and-load controller. (20-3)
25. During isolated generator operation, the frequency-and-load controller maintains constant generator frequency. During parallel operation, the frequency-and-load controller performs the additional function of maintaining an equal real-load division between generators. (20-3, 4)
26. By a network of current transformers. (20-4)
27. To the frequency control on the drive. (20-4)
28. It senses the phase angle between the reference frequency and the generator frequency and provides a proportional signal. (20-7)
29. On the principle of a saturable reactor. (20-12)
30. "Generator error" is the resultant value of magnetic flux of the reference signal and the sensing signal and is used to control the first-stage output of a mag-amp voltage regulator. (20-13)
31. It is the power stage to the exciter field. (20-14)
32. To oppose any change in exciter output voltage due to transient load conditions. (20-15)
33. The voltage regulator. (20-19)
34. There will be a decreasing system voltage as load is applied to the generator. (20-25)
35. The generator control relay. (20-34)
36. The lockout relay. (20-36)
37. The underexcitation relay. (20-40)
38. The overexcitation-underexcitation circuit. (20-40)
39. The OE-UE loop circuit functions only when the generators are paralleled together. (20-42)
40. The bus tie breakers connect the load buses to the synchronizing bus. (21-5)
41. When the generator control relay closes, the exciter field circuit is established, control power is connected to the generator breaker switch when the drive is up to speed, the generator failure light is turned off, and the relay trip coil circuit is armed. (21-7)
42. By placing the generator breaker switch closed, with the auto parallel control relay deenergized, and the external power breaker open. (21-8)
43. The bus tie breakers are opened and the generator breakers are closed. (21-10)
44. By an underspeed switch on the generator drive. (21-13)
45. The main external power receptacle provides for connecting external power to the aircraft and a load bank to the central tie bus. (21-20)
46. Anytime a central tie bus fault occurs. (21-24)
47. The phase sequence relay. (21-27)
48. Through pin F of the external power receptacle which is grounded at the load bank. (21-31)

49. The logical steps required to identify and remedy systems malfunctions are:

(1) Define the problem.
(2) Investigate the problem.
(3) Evaluate the findings.
(4) Determine the exact cause.
(5) Repair or remedy.
(21-36)

50. By performing a complete and thorough operational check of the affected system and then making a written list of possible troubles. (21-39)

51. It makes you less likely to forget any of the possible causes, and it helps point out any causes that are illogical. (21-40)

52. Before removing the component for a bench check, disconnect the connector and use an appropriate meter to test for problems such as a short. (21-44)

53. Defective frequency-and-load control units or the generator drive governor system. (21-51)

54. The voltage output will increase when the throttle is advanced and decrease when the throttle is retarded. (21-54)

55. Lower than normal voltage output from the generator. (21-54)

56. An open in the reactive load equalizing circuit. (21-55)

57. Loss of the reference circuit to the regulator. (21-55)

58. A defective or maladjusted voltage regulator. (21-56)

CHAPTER 6

1. Motor action is a force excited on a current-carrying conductor placed in a magnetic field. (22-3, 4)

2. The factors that control torque are the strength of the magnetic field and armature current. (22-5)

3. When the armature in a motor rotates in a magnetic field, a voltage is induced in its windings. The voltage is opposite in direction to the applied voltage. (22-6-8)

4 In a series motor, the field and armature are connected in such a way that the current in the field also flows in the armature. (22-10)

5. A shunt motor has the best speed control, as it varies very little (22-14)

6. The series field provides good starting torque while the shunt field provides the speed control. (22-15-17)

7 Heat. (22-18)

8. The speed depends on the amount of current which flows through the rheostat in series with the field windings as shown in figure 70, A. An increase in the value of resistance will cause less current to flow through the field which in turn will decrease the field strength. A decrease in field strength will cause a decrease in CEMF. The end result is an increase in armature current-flow and torque. The opposite is true when current is increased in the field circuit because of less resistance in the circuit. (22-23, 24)

9 All that is needed to complete the circuit is a switch and wiring. The reverse current provisions are inside the motor housing that is needed to direct current flow in two directions through the motor. (22-27-29)

10. The three classes of induction motors are: single-phase, two-phase, and three-phase. (23-1)
11. The speed of and induction motor is determined by number of poles and the supply voltage. (23-4)
12. High starting torque. (23-7)
13. A squirrel-cage rotor is used in induction motors. (23-5, 8)
14. An induction motor operates on the principle of a rotating magnetic field. (23-9)
15. Slip is the difference between the rotating magnetic field and rotor speeds. The more load that is placed on the rotor, the more the slip between the rotor and rotating magnetic field increases. (23-11)
16. The synchronous speed of all induction motors is the speed at which the magnetic field rotates. (23-12)
17. Combinations of inductance, capacitance and resistance can be used to split the phase of the motor winding. (23-16)
18. A single-phase induction motor is self-starting because the capacitor causes the currents in two windings—starting and running—to differ in phase by approximately 90°. (23-21)
19. A centrifugal device (switch in most cases) is used to disconnect the starting winding from the circuit when the motor gets up to speed. (23-23)
20. A three-phase induction motor may be reversed by reversing any two power leads. (23-33)
21. A three-phase induction motor will run on only two phases. (23-34)
22. The speed of the rotating magnetic field. The speed of the rotor and magnetic field are locked together and remain the same. (23-35, 36)
23. A rotary inverter consists of a dc motor and an ac generator contained within the same housing (24-1)
24. The output frequency range for inverters is 375 to 425 Hz. (24-3)
25. All inverters take dc power from the motor terminals for excitation of the field because rectified current has a certain amount of ripple which would adversely affect the inverter output. (24-14)
26. The changeover relay. (24-23)
27. The six basic circuits are:
    a. Oscillator circuit
    b. Voltage sensing circuit
    c. Voltage reference circuit
    d. Voltage driver circuit
    e. Push-pull output circuit
    f. Resonant output tank circuit. (25-2)
28. To produce a constant 400-Hz signal. (25-3)
29. A sinusoidal ac signal and a dc reference signal. (25-4)
30. The voltage sensing circuit. (25-8)
31. The voltage sensing circuit and voltage reference circuit. (25-11)
32. Its a series of positive and negative square pulses. (25-12)
33. The pulse width of the output signal will be reduced. (25-18)
34. The magnitude of the output signal will increase. (25-19)

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STOP– 1. MATCH ANSWER SHEET TO THIS EXERCISE NUMBER. 2. USE NUMBER 1 PENCIL.

42351 02 21

VOLUME REVIEW EXERCISE

Carefully read the following:

DO'S

1. Check the "course," "volume," and "form" numbers from the answer sheet address tab against the "VRE answer sheet identification number" in the righthand column of the shipping list. If numbers do not match, take action to return the answer sheet and the shipping list to ECI immediately with a note of explanation.

2. Note that numerical sequence on answer sheet alternates across from column to column.

3. Use only medium sharp # 1 black lead pencil for marking answer sheet.

4. Circle the correct answer in this test booklet. After you are sure of your answers, transfer them to the answer sheet. If you *have* to change an answer on the answer sheet, be sure that the erasure is complete. Use a clean eraser. But try to avoid any erasure on the answer sheet if at all possible.

5. Take action to return entire answer sheet to ECI.

6. Keep Volume Review Exercise booklet for review and reference.

7. If *mandatorily* enrolled student, process questions or comments through your unit trainer or OJT supervisor.
   If *voluntarily* enrolled student, send questions or comments to ECI on ECI Form 17.

DON'T

1. Don't use answer sheets other than one furnished specifically for each review exercise.

2. Don't mark on the answer sheet except to fill in marking blocks. Double marks or excessive markings which overflow marking blocks will register as errors.

3. Don't fold, spindle, staple, tape, or mutilate the answer sheet.

4. Don't use ink or any marking other than with a # 1 black lead pencil.

Note: The 3-digit number in parenthesis immediately following each item number in this Volume Review Exercise represents a Guide Number in the Study Reference Guide which in turn indicates the area of the text where the answer to that item can be found. For proper use of these Guide Numbers in assisting you with your Volume Review Exercise, read carefully the instructions in the heading of the Study Reference Guide.

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Multiple Choice

Chapter 1

1. (200) The total effective plate area in a lead-acid cell determines the

   a. ampere-hour capacity.
   b. closed-circuit voltage.
   c. internal resistance.
   d. open-circuit voltage.

2. (200) When accidently splashed by electrolyte, your first step should be to

   a. call a doctor.
   b. neutralize the electrolyte with boric acid.
   c. thoroughly wash the area with water.
   d. neutralize the electrolyte with baking soda.

3. (200) When mixing electrolyte for lead-acid batteries, the repairman should

   a. mix it in a galvanized container.
   b. pour the acid into the water.
   c. pour the water into the acid.
   d. heat the acid for a better mix.

4. (200) The correct water level of a lead-acid cell is normally established by

   a. a hydrometer.
   b. calculation.
   c. a metal ruler.
   d. a self-leveling syringe.

5. (201) Just *prior* to performing a capacity test of a lead-acid battery, it should be

   a. completely discharged.
   b. overcharged for 2 hours.
   c. low in specific gravity.
   d. allowed to stand for 72 hours.

6. (203) After filling a silver-zinc battery with electrolyte, it

   a. may be put into service immediately.
   b. should be placed on charge immediately.
   c. should be allowed to stand for 72 hours.
   d. requires additional servicing after a 72-hour period.

7. (200) The first step in the preparation of a lead-acid battery for charging is to

   a. add water to the full level.
   b. add electrolyte to fill the cell.
   c. clean the outside of the case.
   d. check the electrolyte level.

8. (202) The proper electrolyte level of a nickel-cadmium battery is

   a. not affected by internal conditions.
   b. 3/8 inch above the top of the plates.
   c. 1/4 inch below the plates.
   d. even with the top of the plates.

9. (203) Before you place a new or used silver-zinc battery on charge, you should inspect the battery for

   a. corrosion.
   b. damaged cells.
   c. loose connections.
   d. all of the above.

10. (201) The charging rate for a 17-ampere-hour battery, a 34-ampere-hour battery, and a 68-ampere-hour battery connected in series should not exceed

    a. 1.7 amperes.
    b. 3.4 amperes.
    c. 4 amperes.
    d. 6.8 amperes.

11. (201) Batteries that fail the capacity test must *not* be used in

    a. battery carts.
    b. testing devices.
    c. ground power equipment.
    d. shop maintenance work.

12. (201) When two successive readings show no increase in specific gravity,

a. remove the battery from the charger.
b. the charging rate should be decreased.
c. the charging rate should be increased.
d. water must be added to the battery.

13. (201) A capacity test is performed on a lead-acid battery to determine the

a. battery's internal condition.
b. charging rate of the battery.
c. specific gravity of the electrolyte
d. specific gravity of the battery.

14. (200) The state of charge of a lead-acid battery is best determined with a

a. voltmeter.
b. hydrometer.
c. hygrometer.
d. capacity tester.

15. (202) A recommended neutralizing agent for the electrolyte used in nickel-cadmium batteries is

a. boric acid.
b. baking soda.
c. sulpheric acid.
d. potassium hydroxide.

16. (203) When charging a silver-zinc battery, the constant-potential method is

a. recommended.
b. never used.
c. an emergency method.
d. the only method authorized.

17. (202) The state of charge of a nickel-cadmium battery is determined by

a. a hydrometer.
b. the charging current.
c. a capacity tester.
d. closed-circuit terminal voltage.

18. (203) The state of charge of a silver-zinc battery is determined by checking the

a. charging current.
b. specific gravity of each cell.
c. closed-circuit voltage of each cell.
d. open-circuit voltage of each cell.

19. (203) When a silver-zinc battery is installed in an aircraft, the dc system must be accurately adjusted to limit the voltage at the battery terminal to a maximum of

a. 18 volts.
b. 24 volts.
c. 26 volts.
d. 28 volts.

Chapter 2

20. (205) Variable dc voltage for the T-35 tester has a range from

a. 0 to 26 volts.
b. 0 to 30 volts.
c. 0 to 45 volts.
d. 0 to 60 volts.

21. (206) What use is made of the 1600-cycle output of the ac electronic generator of the T-170 tester?

a. It provides a signal for parallel operation.
b. It simulates a system with a permenent magnet generator.
c. It provides a signal for testing the auto paralleling unit.
d. It simulates a system using a frequency reference unit.

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22. (206) In the power amplifiers of the T-170 test set, what class of operation are the power triodes operated at when their output is over 60 watts?

a. Class A.
b. Class AB.
c. Class C.
d. Class D.

23. (205) When manually adjusting the frequency of the ac generator on the T-35 tester within 0.1 Hz, the frequency must be between

a. 310 and 440 Hz.
b. 395 and 405 Hz.
c. 390 and 410 Hz.
d. 380 and 420 Hz.

24. (206) The recorder unit supplied with the T-170 tester is used when testing the

a. A-1 exciter regulator.
b. generator control panel.
c. frequency-and-load controller.
d. voltage regulator.

25. (205) Generator control panels should be checked for serviceability on the

a. A-2 test stand.
b. T-31 test set.
c. T-35 tester.
d. T-170 test set.

26. (207) The purpose of the 5-hp motor in the MC-2 test stand is to

a. disengage the brake.
b. start the prime mover.
c. control the 75-hp motor speed.
d. operate the stand with small loads.

27. (209) Any time a unit has been overhauled or is suspected of a malfunction, both before and after repair, it should

a. be ready for installation on the using unit.
b. have a complete functional test before it is declared serviceable.
c. have a functional test in the area that is affected by the maintenance performed.
d. not be functionally tested because maintenance performed by the TO is always correct.

28. (204) Dc generators may be tested at varying speeds and under varying loads on the

a. A-2 test stand.
b. T-31 test set.
c. T-35 tester.
d. T-170 test set.

29. (208) What is the maximum load per phase provided by the A-1 load bank?

a. 13.3 KVAR.
b. 26.6 KVAR.
c. 30 KVAR.
d. 40 KVAR.

30. (207) To test the constant-speed drive and the generator, the repairman should use the

a. MC-2.
b. PSM-6.
c. T-31.
d. T-170.

31. (209) Which of the following test stands will test a 2500-volt-ampere inverter?

a. A-1.
b. A-2.
c. L-1A.
d. MC-2.

32. (204) Dc control panels may be tested on the

a. A-2 test stand.
b. T-31 test set.
c. T-35 tester.
d. T-170 test set.

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33. (206) The operation of the individual power supplies on the T-170 test set is controlled by the

a. card switch.
b. control panel under test.
c. power distribution unit.
d. digital instrumentation system.

34. (208) The maximum resistive and reactive loads that can be provided by the A-1 load bank are

a. 30 kw and 20 KVAR.
b. 30 kw and 40 KVAR.
c. 60 kw and 20 KVAR.
d. 60 kw and 40 KVAR.

35. (209) The inverter test stand referred to in the text will test

a. single-phase inverters only.
b. three-phase inverters only.
c. single- and three-phase inverters.
d. all inverters and rectifiers.

36. (204) When a dc generator is being tested on an unmodified A-2 test stand, how is its output voltage controlled?

a. By a 0- to 10-ampere rheostat.
b. By a 0- to 25-ampere rheostat.
c. With a carbon-pile regulator.
d. By a voltage regulator.

37. (206) An instrument that is useful for bench testing a static voltage regulator is the

a. A-1 test stand.
b. C-1 test stand.
c. T-35 tester.
d. T-170 tester.

38. (206) Functional testing of various ac power-generating system components may be accomplished with the use of an adapted

a. A-2 test stand.
b. T-31 test set.
c. T-35 tester.
d. T-170 test set.

39. (208) The ammeter on the A-1 load bank is protected from damage by

a. a 50-MV shunt.
b. current transformers.
c. opening the ammeter circuit.
d. shorting the ammeter circuit.

40. (206) The card switch used with the T-170 tester sets up the

a. programmer and relay control center to test the component.
b. frequency of the ac electronic generator.
c. recorder unit to test the component.
d. voltage from the variable supply.

Chapter 3

41. (210) The unregulated terminal voltage of a shunt-type generator varies inversely with its

a. speed.
b. load.
c. field strength.
d. load, speed, and field strength.

42. (210) The use of laminated pole tips in the manufacture of generators tends to

a. decrease the reluctance of the pole tips.
b. increase the permeability of the pole tips.
c. increase the retentivity of the pole pieces.
d. decrease the concentration of flux at the pole tips.

43. (212) The primary purpose of the overvoltage relay is to

a. turn on the warning light.
b. trip the field control relay.
c. close the reverse-current relay.
d. open the field to the generator.

Note to Student. For the next 3 items, refer to figure 42 of the text.

44. (215) If you received a writeup on AF Form 781 that the aircraft voltmeter showed 8 volts, you should take the necessary ohmmeter readings at the voltage regulator base. If these readings are 30.5 ohms from A to B, 0.5 ohm from B to ground, and 30 ohms from A to ground, the trouble would most likely be a

a. grounded "A" lead.
b. high resistance in the field.
c. defective voltage regulator.
d. tripped field control relay.

45 (215) With the engine running at cruising rpm, the aircraft voltmeter indicates 0 volts. With the engine stopped and the regulator removed, an ohmmeter check from A to ground on the base reads infinity, from B to ground infinity, and from B to A 3.5 ohms. A possible cause of trouble is an open

a. "b" lead.
b. "E" lead.
c. "voltmeter" lead.
d. ground on the regulator.

46. (215) In a standard 24-volt generator system, the normal armature resistance is 1/2 ohm and the resistance of the field is 3 ohms. If, with the regulator removed from the base, an ohmmeter connected from B to A reads 3 ohms, from A to ground 3 ohms, and from B to ground 0 ohms, a possible cause of trouble is

a. an open "a" lead.
b. an open "B" lead.
c. a grounded "B" lead.
d. a shorted "B" to "a" lead.

47. (213) The component in the generator control system that can be manually closed is the

a. overvoltage relay.
b. voltage regulator.
c. differential relay.
d. field control relay.

48. (210) What feature of a generator compensates for armature reaction by weakening the flux produced by the armature current?

a. Shunt field.
b. Series field.
c. Slotted pole pieces.
d. Plasticized pole tips.

49. (214) Flashing the field of a dc generator may be used to

a. correct field polarity.
b. increase field resistance.
c. destroy residual magnetism.
d. reverse the current to the RCR.

50. (212) One function of a differential-type relay is to

a. connect the generator to the distribution system when generator voltage is higher than bus voltage
b. disconnect the battery from the distribution system when battery voltage is lower than bus voltage
c. connect the battery to the distribution system when battery voltage is lower than bus voltage
d. disconnect the generator from the distribution system when generator voltage is higher than bus voltage

51. (212) The bimetallic compensating ring in the carbon-pile voltage regulator compensates for an increase in temperature by

a. increasing the pressure on the carbon stock.
b. decreasing the pressure on the carbon stock.
c. decreasing the pressure on the adjustable core
d. increasing the pressure on the adjustable core

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52. (210) The interpole windings in a generator are

a. adjustable for varying loads.
b. used to reduce armature reaction.
c. connected in parallel with the armature.
d. used to increase the emf of self-induction.

53. (213) In a multi-generator system, load division is performed by the equalizing resistor and the

a. differential relay.
b. field control relay.
c. voltage regulator.
d. reverse-current relay.

54. (212) Resistance varies inversely with temperature in

a. steel.
b. brass.
c. silver.
d. carbon.

55. (210) Which of the following types of generators always has an output voltage which increases as the load increases?

a. Series-wound.
b. Shunt-wound.
c. Flat-compound.
d. Separately excited.

56. (214) If an aircraft voltmeter connected from B to ground reads between 1 and 2 volts with the engine running at cruising rpm, there is likely to be a fault in the

a. field circuit.
b. ammeter circuit.
c. voltmeter circuit.
d. equalizing circuit.

57. (211) Which of the following is often used to test a dc generator armature for an open circuit?

a. Test lamp.
b. Growler.
c. Voltmeter.
d. High-pot tester.

58. (212) If the fixed resistor in the voltage coil circuit of a carbon-pile regulator should open, the generator output voltage would be

a. low because the carbon stock resistance would be at minimum.
b. low because the carbon stock resistance would be at maximum.
c. excessive because the carbon stock resistance would be at minimum.
d. excessive because the carbon stock resistance would be at maximum.

59. (212) When the red warning light in a generator warning system is illuminated, it indicates that the field control

a. reset relay has been energized and the generator field is complete.
b. reset relay has been energized and the generator field is open.
c. trip relay has been energized and the generator field is complete.
d. trip relay has been energized and the generator filed is open.

60. (214) If a dc generator system has a high uncontrollable output whether or not the voltage regualtor is in the circuit, a possible cause of the trouble is

a. an open voltage coil.
b. a shorted shunt field coil.
c. an open in the field circuit
d. a shorted field circuit B to A.

61. (211) Which of the following is best for removing minor burnt spots on a generator commutator?

a. Crocus cloth.
b. Emery paper.
c. Sandpaper.
d. A fine file.

62. (214) With the engine running at cruising rpm, the aircraft voltmeter indicates zero voltage Which of the following is the most likely cause?

a. A dirty commutator.
b An open "g" lead.
c. A short between "A" and "B."
d. A short between "a" and "b."

Chapter 4

63. (217) A transformer-rectifier unit is used to provide dc power

a. to the emergency dc bus.
b. for ground operations only.
c. when the aircraft primary power source is ac.
d. when two or more inverters are operating in parallel.

64. (218) For what purpose would a repairman short the four input terminals of a transformer-rectifier unit together and the two output terminals together?

a. To determine the voltage drop across the rectifiers.
b. To determine the inverse voltage across the diodes.
c. To perform an insulation breakdown test.
d. To perform a voltage regulation test.

65. (217) An important item of preflight inspection in regard to installed transformer-rectifier units is the

a. polarity of the output power.
b. proper paralleling of the units.
c. correct input power.
d. direction of airflow.

66. (218) A battery charging transformer-rectifier unit is capable of producing its highest output voltage at a load of

a. 0 amperes.
b. 10 amperes.
c. 25 amperes.
d. 100 amperes.

67. (217) In the battery charging transformer-rectifier unit discussed in the text,

a. both control windings are in series with the load.
b. CW2 is used to bias CW1 and minimize circulating currents.
c. the output voltage is minimum when the cores are saturated.
d. the output voltage is maximum when the cores are saturated.

Chapter 5

68. (221) The output voltage of the type B-1 variable-frequency ac generator is controlled by the

a. rocker ring.
b. voltage regulator.
c. exciter regulator.
d. transformer-rectifier.

69. (222) Which of the following is a *must* during the repair and testing of aircraft generators?

a. The use of technical orders.
b. A sufficient manpower pool.
c. The manufacturer's descriptive literature.
d. Available replacement parts and subassemblies.

70. (220) The output frequency of an ac generator is determined by the

a. number of armature conductors.
b. strength of the magnetic field.
c. speed and direction of generator rotation.
d. speed of coil rotation and number of field poles

71. (226) What function do the mutual reactors perform when a generator goes into an overvoltage condition during parallel operation?

a. They boost the voltage sensed from the underexcited generators.
b. They decrease the voltage sensed from the overexcited generators.
c. They boost the voltage sensed from the overexcited generators.
d. They have no effect on the voltage sensed from the underexcited generators.

72. (229) According to systematic troubleshooting procedures, writing down the possible troubles is a methodical way of

a. defining the problem.
b. evaluating the findings.
c. investigating the problem.
d. determining the exact cause.

73. (221) In what general speed range do variable-frequency generators operate?

a. 390 to 420 rpm.
b. 800 to 1000 rpm.
c. 3000 to 9000 rpm.
d. 3800 to 10,000 rpm.

74. (224) The auto parallel unit will operate only if the generators to be paralleled are

a. slightly out of phase.
b. synchronized in phase.
c. more than 6 Hz apart.
d. more than 8 Hz apart.

75. (225) The opening voltage of the starting relay in the mag-amp voltage regulator discussed in the text is approximately

a. 95 volts phase-to-ground.
b. 125 volts phase-to-phase.
c. 185 volts phase-to-ground.
d. 195 volts phase-to-phase.

76. (223) The sprag-type clutch in the constant-speed drive (CSD) functions to allow the

a. generator to turn slower than the CSD output shaft.
b. generator to turn faster than the CSD output shaft.
c. aircraft engine to turn faster than the CSD input shaft.
d. aircraft engine to turn slower than the CSD input shaft.

77. (220) How many poles would you expect to find in an ac generator operating at 4800 rpm and a frequency of 400 Hz?

a. 6 poles.
b. 8 poles.
c. 10 poles.
d. 12 poles.

78. (223) It is a function of the limit governor on a constant-speed drive to

a. detect an overspeed or underspeed condition and to operate the pressure switch.
b. control the speed of the drive by changing the angle of the pump wobbler
c. establish a basic reference frequency of 395 Hertz from any armature speed.
d. control the speed of the drive by changing the angle of the motor wobbler.

79. (227) In the multi-generator system using a constant-speed drive, during normal engine shutdown, the generator breaker will be tripped by the

a. lockout relay.
b. exciter switch.
c. generator switch.
d. underspeed switch.

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80. (225) During parallel operation of an ac generator system, one generator is carrying an excessive amount of KVAR load. A malfunction in which system component would most likely cause this?

a. Constant-speed drive.
b. Voltage regulator.
c. Exciter control relay.
d. Frequency-and-load controller.

81. (226) Protection against generator overvoltage during parallel operation is provided by the

a. voltage regulator.
b. overvoltage relay.
c. overexcitation relay.
d. exciter protection relay.

82. (227) When a load bank is used to perform an operational check of the ac power system, it is connected to the aircraft

a. directly to the central bus.
b. directly to the generator bus.
c. through the generator quick-disconnect.
d. through the external power system.

83. (229) According to the text, the first step in troubleshooting an electrical system is to

a. investigate the problem.
b. define the problem.
c. evaluate the findings.
d. determine the exact cause.

84. (224) When generators are connected in parallel, the kw load is divided equally by the

a. voltage regulator.
b. constant-speed drive.
c. generator protection unit.
d. frequency-and-load controller.

85. (220) An increase in the KVAR load of an ac generator requires a corresponding change in

a. frequency.
b. horsepower.
c. excitation.
d. power factor.

86. (222) What is the purpose of the commutating diode installed in the rear end bell of a brushless ac generator?

a. Reduce negative voltage spikes.
b. Suppress rectifier peak inverse voltage.
c. Rectify PMG output to the control panel.
d. Rectify the ac voltage to the generator field.

87. (228) Paralleling of an aircraft generator and the external power generator is prevented by the

a. disarm relay.
b. interlock relay.
c. lockout relay.
d. generator control relay.

88. (220) Increasing the resistive load on a constant-frequency ac generator requires an increase in the

a. speed of the generator.
b. exciter-generator output.
c. torque output of the drive unit.
d. voltage output of the generator.

89. (227) During load bank operation, pin F of the external power receptacle provides

a. a ground for the disarm relay.
b. a ground for the interlock relay.
c. dc power for lockout relay operation.
d. dc power for operation of the external power circuit breaker relay.

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90. (223) The pumping action of the wobbler pump in a constant-speed drive unit is at minimum when

a. it is in an overdrive condition.
b. it is in an underdrive condition.
c. it is in straight-through condition.
d. the aircraft engine is in the minimum speed range.

91. (227) The phase sequence relay in the multi-generator external power system controls the external power

a. disarm relay.
b. control relay.
c. lockout relay.
d. interlock relay.

92. (222) One of the characteristics of wye-connected ac generators is that they have

a. three available voltages.
b. three windings connected in series.
c. three windings connected in parallel.
d. single-phase and three-phase voltages available.

93. (225) The boost current transformers used with a mag-amp voltage regulator

a. increase the regulator maximum output limit.
b. limit the regulator input to the first stage only.
c. limit the regulator input during all load conditions.
d. decrease the regulator output during short circuit conditions.

94. (220) When a leading power factor load on an ac generator is increased, the

a. exciter output will decrease.
b. field current will increase.
c. terminal voltage will decrease.
d. torque output of the drive will increase.

95. (226) The unit in an ac power system that protects the generator in case the current flow in two leads of the same phase is not equal is the

a. overexcitation relay.
b. underexcitation relay.
c. differential fault relay.
d. exciter protection relay.

96. (223) In the linear-type constant-speed drive discussed in the text, when the displacement of the pump is greater than the displacement of the motor, in what condition is the drive?

a. Motorized.
b. Overdrive.
c. Underdrive.
d. Straight-through.

97. (227) What component in the generator control system must be closed before there can be any generator output?

a. Bus tie breaker.
b. The generator breaker.
c. The auto paralleling relay.
d. The generator control relay.

98. (225) Loss of the sensing signal (57 vdc) in the mag-amp voltage regulator will cause

a. system voltage to go to maximum.
b. system voltage to go to 100 volts.
c. the regulator output to go to zero.
d. the regulator input to go to maximum.

99. (223) A constant-speed drive cannot be placed back into operation during flight if it has shut down due to an

a. underspeed condition.
b. overspeed condition.
c. underdrive condition.
d. overdrive condition.

100. (226) A paralleled generator is automatically placed in isolated operation through the operation of the

a. lockout relay.
b. undervoltage relay.
c. generator control relay.
d. differential fault relay.

Chapter 6

101. (230) To do a job which requires a constant-speed motor that need not have a high starting torque, what type of motor would you select?

a. Shunt motor.
b. Series motor.
c. Compound motor.
d. Continuous duty motor.

102. (233) A synchronous motor differs from an induction motor in that in the synchronous motor

a. ac current is supplied to the rotor.
b. dc current is supplied to the stator windings.
c. rotor speed is usually less than the rotating field.
d. the rotor turns at the same speed as the rotating field.

103. (230) Which of the following will result if the power leads are reversed while a dc series-wound motor is in operation?

a. The field will burn out.
b. The armature will burn out.
c. The motor will turn in the opposite direction.
d. The armature will continue to rotate in the same direction.

104. (234) The resistance of the flyweight controlled carbon pile used on inverters is dependent on

a. frequency of input.
b. type of carbon used.
c. the flyweight material.
d. pressure and temperature.

105. (231) The rotor circuit in a squirrel cage motor is supplied with current through

a. mutual induction.
b. the rotor shaft.
c. self-induction.
d. counter-electromotive force.

106. (230) What change takes place in the field flux and the armature speed as the load is removed from a series motor?

a. They both increase.
b. They both decrease.
c. They increase and decrease, respectively.
d. They decrease and increase, respectively.

107. (235) A change in the inverter output voltage is normally detected by the

a. oscillator circuit.
b. voltage sensing circuit.
c. voltage driver circuit.
d. voltage reference circuit.

108. (231) The current in the rotor of a single-phase induction motor is produced by

a. exciters.
b. sliprings.
c. a commutator.
d. mutual induction.

109. (230) Motor action will result when a conductor is placed in a magnetic field if the

a. conductor is carrying current.
b. magnetic field is parallel to the conductor.
c. magnetic field is produced by permanent magnets.
d. conductor is under the geometric center of the pole

110. (230) If the voltage applied to a motor is 220 volts and the counter-emf is 200 volts, what will be the current through an armature whose resistance is 4 ohms?

a. 0.05 ampere.
b. 0.5 ampere.
c. 5 amperes.
d. 50 amperes.

111. (231) In comparing a three-phase squirrel cage induction motor with a transformer, it could be said that the rotor is comparable to the

a. primary of a step-up transformer.
b. primary of a step-down transformer.
c. secondary of a step-up transformer.
d. secondary of a step-down transformer.

112. (230) Usually, the field magnets of a dc motor are

a. electromagnets.
b. permanent magnets.
c. made of laminated steel.
d. solid cylindrical-shaped magnets.

113. (230) Which of the following would be the most practical method of increasing the speed of a shunt-wound motor?

a. Decreasing the number of windings in the shunt field.
b. Decreasing the resistance in series with the shunt field.
c. Increasing the resistance in series with the shunt field.
d. Increasing the resistance in series with the armature windings.

114. (230) Assuming a constant field flux, what is the effect of an increase in motor armature speed on the counter-emf and the armature current?

a. Both forces decrease.
b. Both forces increase.
c. The forces decrease and increase, respectively.
d. The forces increase and decrease, respectively.

115. (235) The output signal from the push-pull output circuit of the static inverter is dependent upon the

a. input pulses.
b. input to Q8.
c. output of Q7.
d. output of T3.

116. (231) When a dc motor is compared with a simple induction motor, it should be noted that the

a. brushes of both motors are shorted.
b. former has a commutator, whereas the latter has sliprings.
c. former has a stationary magnetic field; the latter has a rotating magnetic field.
d. former uses a shaded pole; the latter uses a split field for reversing.

117. (231) In an induction motor, if the number of pairs of poles is divided by two and the frequency of the applied voltage is doubled, the synchronous speed is

a. unaffected.
b. divided by four.
c. multiplied by two.
d. multiplied by four.

118. (232) A capacitor-start motor which is to operate continuously for a considerable length of time may require a

a. centrifugal switch.
b. vast amount of stored dc.
c. long-lasting dc generator.
d. higher voltage than a resistance-start type.

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119. (231) The speed of a three-phase squirrel cage motor can be varied by changing the number of poles in the stator and the

a. phase-winding connections.
b. resistance in the rotor circuit.
c. amplitude of the applied voltage.
d. frequency of the applied voltage.

120. (233) One difference between single-phase and three-phase ac motors is that

a. single-phase motors have a greater torque potential.
b. three-phase motors must have some type of starting aid.
c. single-phase motors must have some type of starting aid.
d. single-phase motors will operate faster than three-phase motors.

121. (234) In most inverters, a voltage regulator controls the

a. current through the armature.
b. current through the motor field.
c. current through the generator field.
d. output voltage by controlling the frequency.

122. (234) The frequency of the rotary inverter that incorporates the voltage regulator circuit can be adjusted by adjusting the

a. voltage regulator.
b. aircraft dc voltage.
c. voltage applied to the motor shunt field.
d. voltage applied to the motor control field.

123. (232) The degree of phase shift during the start of a capacitive start motor is approximately

a. 20°.
b. 30°.
c. 90°.
d. 120°.

124. (235) The reference voltage applied to the input of the voltage driver circuit in the static inverter is established by the

a. oscillator circuit.
b. voltage reference circuit.
c. voltage sensing circuit.
d. push-pull output circuit.

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Course 42351

AIRCRAFT ELECTRICAL REPAIRMAN

(AFSC 42350)

Volume 3

Aircraft Control and Warning Systems

2-1

Extension Course Institute

Air University

Preface

THIS IS THE final volume of this course. In many ways you might consider it the most important volume in the course because it deals with a variety of the electrical systems you are required to maintain. In this volume you will be able to apply the information previously learned directly to a system component. The systems used here are typical systems and are not to be considered for a specific aircraft.

Chapter 1 discusses landing gear systems. Although most landing gears are hydraulically operated, they have been included for good reasons. First, most landing gears are electrically controlled. This is where you, the aircraft electrician, come into the picture. Second, you are required to adjust an calibrate the various switches and actuators in the system so that the gears will operate in the correct sequence. This chapter will provide you with the necessary information to do this.

A great deal of your time will be spent in maintaining the electrical portions of flight control systems, warning systems and fuel systems. To help you perform operational checks, troubleshooting, and the necessary testing of the components in these systems, they are covered in detail in Chapters 2, 3, and 4.

Your duties as an aircraft electrician will also include working on engine starter and ignition systems. Chapter 5 discusses reciprocating engine starters and the various types of fuel-air and pneumatic starters used on jet engines. Test and repair of these components are also covered. In addition to these systems, you will find information concerning cowl-flap system, oil-cooler flap actuator system, and water injection system circuits.

In the final chapter you will find a detailed discussion of aircraft lighting systems, both internal and external. The final portion of chapter 6 deals with the window anti-icing circuits.

Bound in the back of this volume are 6 schematics. Whenever you are referred to one of these figures in the text, please turn to the back of the volume and locate that figure.

If you have questions on the accuracy or currency of the subject matter of this text, or recommendations for its improvement, send them to Tech Tng Cen (TSOC), Chanute AFB, Illinois 61868.

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Material in this volume is technically accurate, adequate, and current as of April 1970.

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Landing Gear and Associated Systems

AIRCRAFT LANDING gear systems are fairly complex because of the many requirements that must be met. For example, all landing gear systems must have safety circuits to prevent accidental operation of the gear when the aircraft is on the ground. Landing gear systems must also have a warning system so that the pilot does not attempt to land the aircraft with the landing gear retracted. Another requirement is that the landing gear system be equipped with an indicating system to show the pilot the position of the landing gear, i.e., up and locked, down and locked, or in an unsafe position. In addition, most landing gear systems have antiskid protective devices that reduce the possibility of a blown tire during landing.

2. What does this mean to you as an aircraft electrician? Although most landing gear systems are hydraulically operated, some are electrically controlled. This means that you are responsible for maintaining the electrical components of landing gear systems. You must be able to troubleshoot the systems, bench-test the components, and make adjustments of limit switches and other components as necessary. You are also required to make operational checks of landing gear systems. This means that you must have an intimate knowledge of the various types of landing gear systems.

3. Now let us discuss a typical heavy aircraft landing gear system and learn how each control and warning circuit contributes to the safe operation of the landing gear.

1. Heavy Aircraft Landing Gear System

1-1. The typical landing gear system selected for the first part of this discussion is a tricycle landing gear system consisting of two four-wheel truck main gears and a steerable dual-wheel nose gear. The gears are hydraulically operated and controlled simultaneously from a single control lever located on the pilot's instrument panel. Each gear is hydraulically and mechanically locked when in either the full UP or full DOWN position.

1-2. The landing gear circuits consist of the landing gear lever lock circuit, antiskid system circuit, nose gear centering switch, main gear safety switches, main gear truck leveling switches, landing gear position and indicating warning system, landing gear throttle warning switches, and door lock and door position switches. These items provide the necessary controls and information for accurate monitoring of landing gear conditions.

1-3. Now we shall discuss each circuit so that you can see how each part of the system functions.

1-4. **Landing Gear Lever Lock Circuit.** The landing gear control lever is locked in the down position to prevent inadvertent operation of the landing gear when the aircraft is on the ground and to prevent retraction of the gear when the nosewheel gear is not centered or when either main gear truck is not level. As shown in figure 1, a spring-loaded solenoid releases the lock on the landing gear control lever when conditions are safe for gear operation. When conditions are safe for gear operation, the lock solenoid is energized by action of five protective switches tied in series from a power source through the solenoid to ground. Before the lock solenoid can energize, the following switches must close: (see fig. 1) the nose centering switch (indicating nose gear is centered); main gear safety (squat) switches (indicating weight of the aircraft is off the main gear, shock struts extended); and the main gear truck leveling switches (indicating that the main trucks are level or perpendicular to the shock strut). An override trigger on the control lever permits release of the lever lock in event the solenoid fails to operate.

1-5. *Nose landing gear centering switch.* The nose gear centering switch, shown in figure 1, is a low-travel, hermetically sealed microswitch located to contact a cam rim, with centering detent, on the steering control cable drum under the pilot's floor. The switch is tied in series with

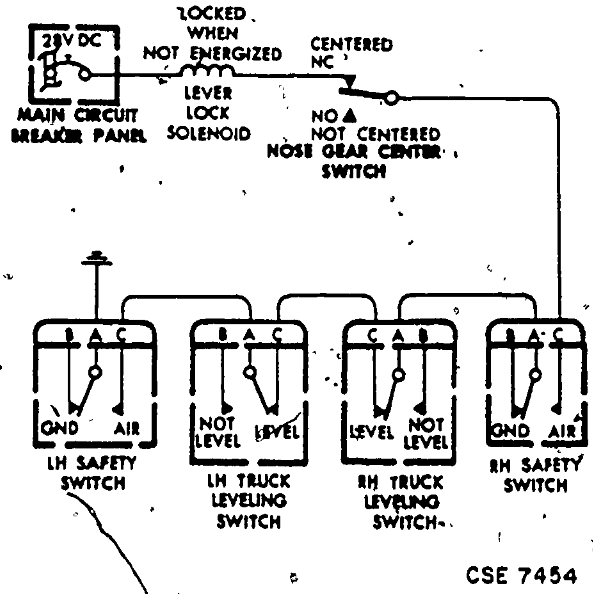

Figure 1. Landing gear lever lock circuit.

the main gear leveling and safety switches to control the lever lock solenoid and prevent gear retraction until the nose gear is properly centered. The switch is closed only when the switch actuator arm is in the detent of the pulley cam rim. Slotted mounting holes in the switch mounting bracket provide the adjustment to obtain the required position for the switch actuation.

1-6. *Main landing gear safety switches.* The main gear safety switches, shown in figure 1, control the lever lock solenoid to prevent operation of the landing gear when the weight of the aircraft is on the gear. The switch for each main gear is a microswitch which is positioned by the upper torsion link on the gear assembly. The circuit through the switch is closed when the strut is extended and opened when the shock strut is compressed. The main gear safety switch mountings are jig located and the actuating linkage fixed so that the switches do not require any adjustment.

1-7. *Main gear truck leveling switch.* The two truck leveling switches (one on each main gear) are connected in series with the two main gear safety switches and the nose gear centering switch in controlling the control lever lock to prevent gear retraction when the gear trucks are out of level (see fig. 1). The leveling switch is on the main gear truck with an actuator linkage connected to the inner cylinder fork. The switch mounting position is jig-located so that there is no adjustment required. When the truck is out of level (not perpendicular to shock strut) beyond safe limits for retraction, the switch will be open to prevent the landing gear control lever from unlocking.

1-8. Earlier in this discussion you learned that all landing gear systems must include a means of showing gear position and a warning system to inform the pilot of unsafe gear conditions.

1-9. **Landing Gear Position and Warning System.** Figure 2 shows a schematic of the position and warning system. A red warning light in the end of the landing gear lever and a warning horn in the cockpit are provided for warning of unsafe gear conditions. The warning light will illuminate at any time the landing gear lever and landing gear position are out of phase. The light is turned on by the landing gear lever position switches when the control lever is placed in the UP or DN position, and it will remain on if any one of the landing gear lock switches is closed (UNLOCKED position), any one of the landing gear door lock switches is closed (UNLOCKED position), or if either of the main gear door position switches is in the door open position. (See fig. 2.) These switches are provided with an adjustment setscrew which is meant for factory adjustment only and should not be reset in the field. Operation of the warning horn is controlled through throttle switches and warning relays so that the horn will sound whenever any one of the landing gears is in any position other than down and locked and any one of the throttle controls is aft of the middle set of scribe marks located on the throttle quadrant. This is the same warning horn that is actuated by the spoiler and flap warning switches. The warning light also operates in conjunction with the horn and is also controlled by the throttle switches and warning relays.

1-10. *Landing gear position indicators.* Three position indicators, shown in figure 2, show the position of each landing gear. Each indicator is controlled by a position-indicating switch and lock switch located within the wheel well of the respective landing gear. When the landing gear is up and locked, the indicator reads UP. When the gear is intransit and until the gear reaches the full up or down-and-locked position, the indicator shows diagonal stripes. With the gear down and locked, the indicator shows a landing wheel. The indicators are magnetic type indicators, spring-loaded to the power off, or intermediate position (diagonal stripes).

1-11. *Control level position switches.* (See fig. 2.) Two microswitches actuated by the landing gear control lever are connected to turn on the warning light when the landing gear control lever is moved from the full UP or DN position. The switches are mounted forward of the landing gear control lever so that the applicable switch is actuated only when the landing gear control lever is in the UP or DN detent of the lever lock plate. The lower switch provides a ground to the warning light through the warning relay contact

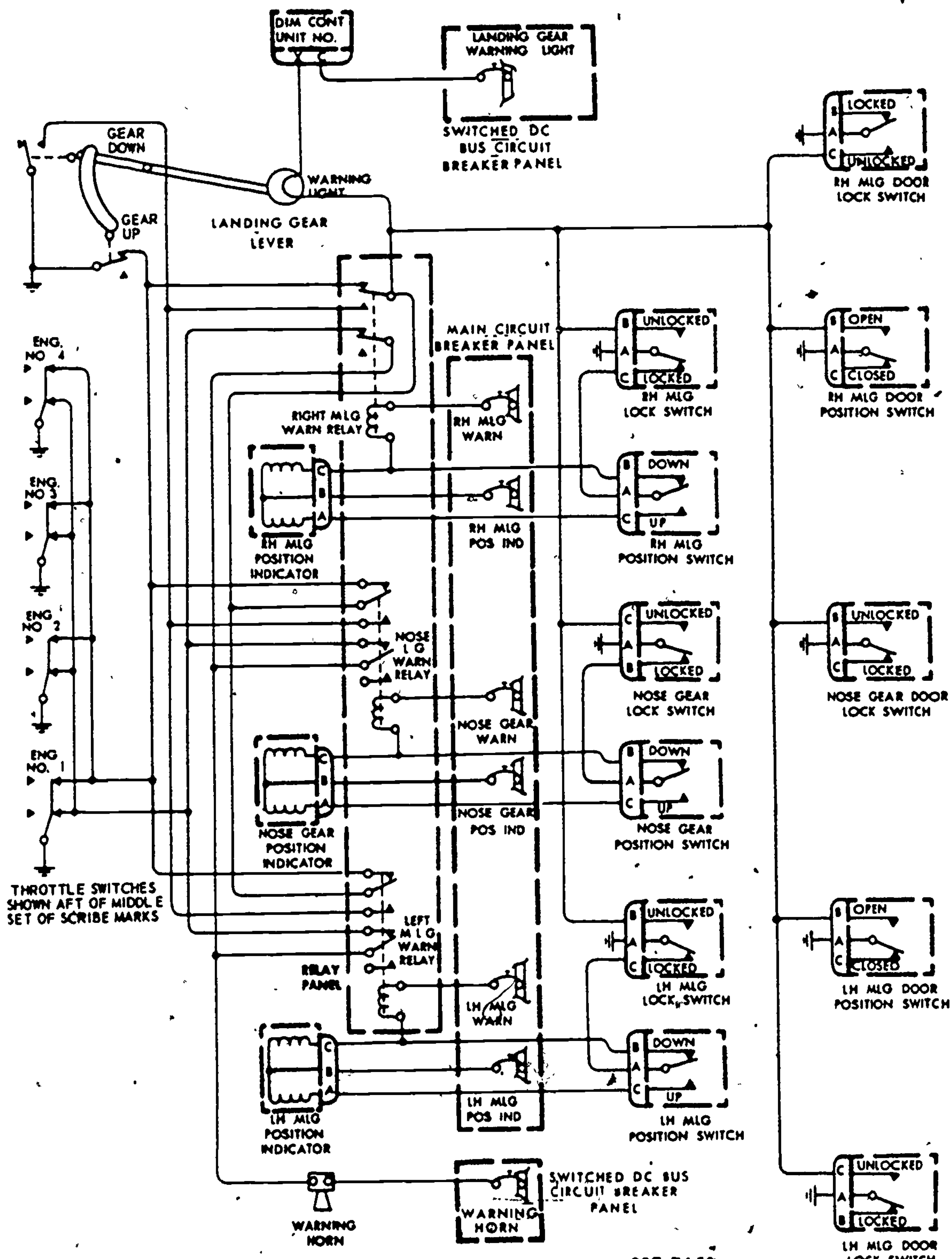

Figure 2. Landing gear position and warning system.

(fig. 2) with the lever in the DN position; and with the lever in the UP position, a ground is provided by the upper switch through the warning relay contact. Proper actuation of the switches is accomplished by adjustment slots in the switch supporting brackets.

1-12. *Landing gear throttle warning switch.* A microswitch for each throttle provides for throttle position control of the landing gear warning light and warning horn. An actuating cam on each throttle cable is arranged so that it actuates the switch when the throttle is retarded. On a landing approach, during which any one of the landing gear position or lock switches remains open, the respective landing gear warning relay remains deenergized. Retarding one or more of the throttles past the middle set of scribe marks on the throttle quadrant closes the landing gear throttle switch, providing a ground which causes the warning light and warning horn to become energized until all gears are fully down and locked. A mechanical cutout button (not shown) is provided for horn cutout. Pushing the button mechanically opens the throttle switches to deenergize the horn. Advancing the throttle, or throttles, again resets the warning horn throttle switches. Slotted holes in the switch support assembly provide a means for switch adjustment.

1-13. *Landing gear warning relays.* (See fig. 2.) The main landing gear warning relays (one for each gear) are two-pole, double-throw, hermetically sealed relays controlled by the main landing gear position-indicating and locking switches. The nose gear warning relay is a four-pole, double-throw, hermetically sealed relay that is controlled by the nose landing gear position-indicating and locking switches. All relays are energized to open the warning horn circuit and a part of the warning light circuit when the respective landing gears are in the fully down-and-locked position. All landing gear warning relays must be energized to avoid warning horn operation when the throttles are retarded.

1-14. *Landing gear position indicating switches.* The two main landing gears and the nose landing gear are provided with position-indicating switches, tied in series with a landing gear lock switch, to transfer the lock control between the up and down indicator circuits. In the GEAR LOCKED position, the lock switch provides a ground to the position indicators through the position switch (see fig. 2). The switches for the main gear are actuated by the main gear lock mechanism as the side strut roller contacts the actuator arm. The nose gear position switch is actuated by a linkage attached to the nose gear drag brace.

1-15. *Landing gear lock switches.* The landing gear lock switches are microswitches mechanically linked to the lock mechanism of each gear. The switches provide the ground necessary for position indicator operation, through the gear position switch, when the gear is locked. As shown in figure 2, when any gear is in the UNLOCKED or in the TRANSIT position, the ground is removed from the position indicators and transferred to the warning light circuit until the gear is up and locked or down and locked. The main gear lock switches are on the forward side of the aft wall in the strut portion of the main gear wheel well while the nose gear lock switch is on the nose gear drag brace directly below the nose gear position switch. The main gear lock switch is actuated by movement of the lock plate as the side strut roller enters the lock plate detent. The nose gear lock switch is actuated by the nose gear drag brace knuckle.

1-16. *Door lock switches.* Each landing gear wheel well door has a lock switch that is in the circuit with the door position and the gear lock switches to control operation of the landing gear warning light in the control handle. The circuit through the door lock switch is opened only when the door is fully closed and the door lock is actuated, as shown in figure 2. The main gear door lock switches are attached to the upper end of their respective door actuator and are operated by the actuator door-lock rod. The nose gear door lock switch is on a bracket at the forward end of the nose wheel well and is actuated by a linkage of the door lock. The main gear door lock switch requires adjustment, but the nose gear door lock switch is jig-located.

1-17. *Door position switches.* As shown in figure 2, only the main gear wheel well doors have a position switch. The circuit is closed through the normally closed switch contacts to the warning light whenever the doors are open. The switches are hermetically sealed microswitches mounted on the keel beam near the forward end of the wheel well. The switches are actuated by the wiping action of the door walking beam at the DOOR CLOSED position. No adjustment is required on the door position switches, since the mounting is jig-located.

1-18. Now that you are familiar with the position and warning system for a typical landing gear system, we may turn our attention to an antiskid control system.

1-19. **Antiskid Control Circuit.** The antiskid control circuit is controlled by a guarded ANTISKID switch on the instrument panel. The antiskid system consists of a skid detector on each wheel and an antiskid control shield and dual antiskid solenoid valve for each gear. Operation of the antiskid solenoid control circuits is completely automatic. The only action required of the pilot, after placing the ANTISKID switch in the ON

position and the landing gear control lever in GEAR DOWN position (while the aircraft is still airborne), is to depress the rudder pedals to meter hydraulic pressure to the brakes. The skid detector sends an electrical signal through the antiskid shield controls to the solenoid valves which relieve brake system pressure when a wheel-skidding condition is detected. As the skid detector contacts close, the solenoid valve is energized and shuts off hydraulic brake pressure to the affected wheel.

1-20. *Skid detector.* The skid detector is a flywheel type inertia mechanism that can detect loss or recovery of synchronous main landing gear wheel speeds. The detector is shown in figure 3. The purpose of the detector is to provide an electrical signal to the solenoid-operated antiskid valve which relieves brake system pressure when a wheel skidding condition is detected. The detector is sealed within a case and mounted coaxially on the outboard side of each main landing gear wheel. A shaft driven by a drive arm attached to the torque plate extends through the center of the detector and rotates with the wheel. The detector flywheel is mounted concentrically with and is driven by the shaft through a spring-loaded ball clutch. If the aircraft wheel speed decelerates relative to the flywheel speed, the

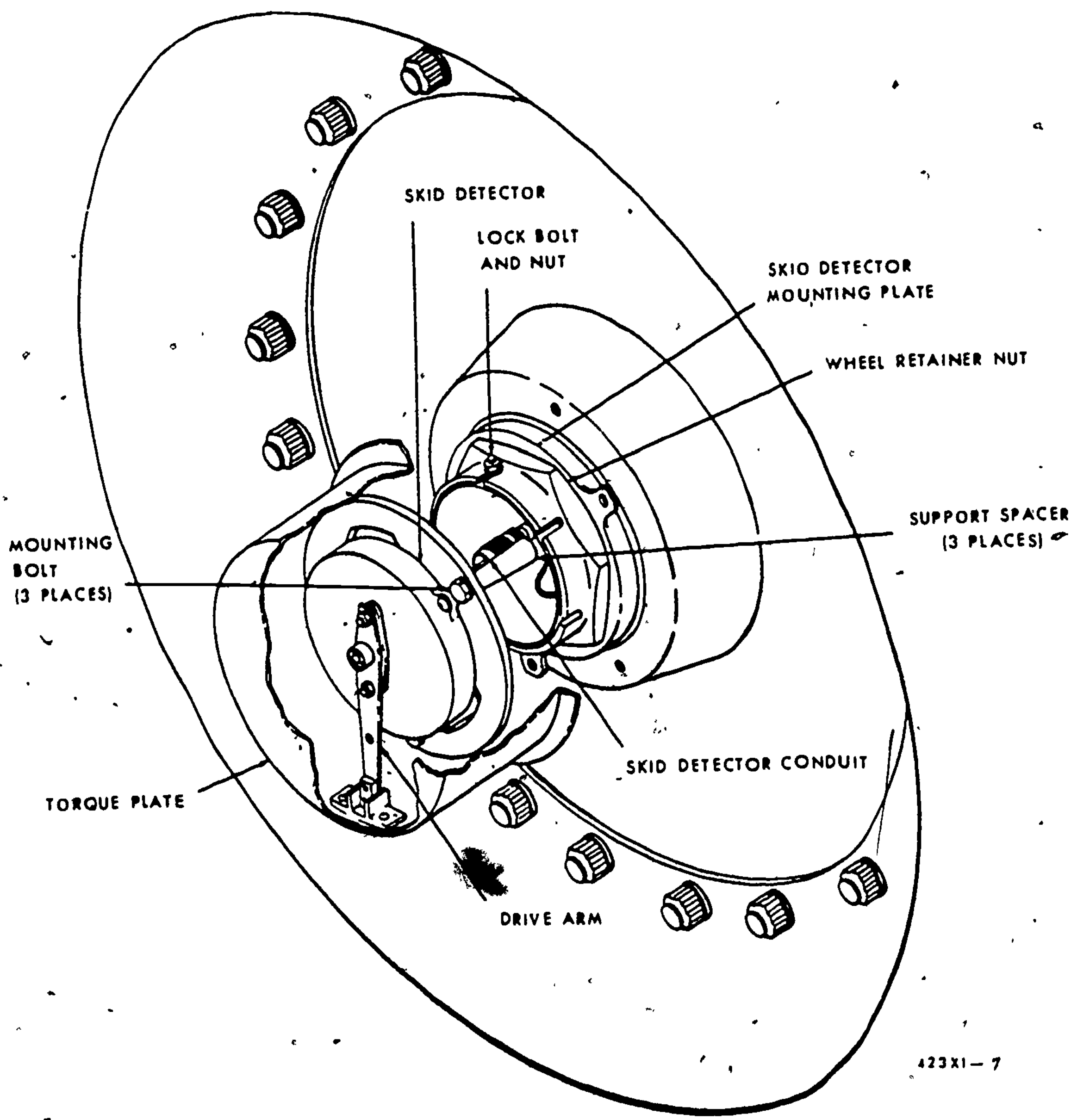

Figure 3. Skid detector.

detector skid contacts close. This action energizes the antiskid valve, which releases brake system hydraulic pressure and prevents the skid. This permits the landing gear wheel to accelerate relative to the flywheel. If a skid continues until a wheel locks, the V relay for that wheel will be deenergized. This provides a ground at pin D of the antiskid control shield for the W relay through the V relay contacts (shown in fig. 4) of the other wheel as long as that relay is energized. This action energizes the antiskid solenoid valve for the locked wheel, shutting off hydraulic pressure to the brake. When the locked wheel signal ends, the time-delay period of the W relay will be increased by the discharge capacitor (through the series resistor) that is connected in parallel with the W relay coil. Thus the wheel will have to reach nonskid speed before brake pressure may be applied again. The flywheel clutch torque and inertia characteristics are such that the flywheel can decelerate at a rate slightly less than the wheel during maximum braking.

1-21. *Antiskid control shields.* The function of the antiskid control shields in conjunction with the skid detectors and antiskid solenoid valves may be traced by referring to figure 4 and the following example of a typical approach and landing roll. While the aircraft is still airborne, the ANTISKID power switch is guarded in the ON position, and the landing gear control lever is placed in the GEAR DOWN position. Power is then directed through the switches to the antiskid control shield for each main gear. While airborne, with the main gear shock struts fully extended, the squat switch relays should energize. This action completes the ground circuit for the W relays through the normally closed contacts of the V relays and the normally open contacts on the squat switch relays. As long as the W relays are energized, power is supplied to the antiskid solenoid valves. With the antiskid valves energized, hydraulic pressure is blocked from the brakes, even though the rudder pedals are depressed. When the wheels touch down and turn at a speed corresponding to 8 mph or more, the commutators in the skid detectors turn. The pulses of current energize the V relays, which break the ground circuits of the W relays. A delay of 1.00 (±, 0.25) second in the W relay dropout prevents application of hydraulic pressure through the antiskid solenoid valve until the wheel turns at a speed corresponding to that of the aircraft. If the wheel decelerates too rapidly, as in a skid, the skid contacts close in the skid detector, providing a skid signal in the form of a ground for the W relay. Power then energizes the antiskid solenoid valve, cutting off hydraulic pressure to the brake of that wheel. At the end of a skid signal, the W relay should drop out after a 0.10 (± 0.5)- second delay and remove power from the antiskid solenoid valve, allowing brake pressure to the wheel.

1-22. *Testing.* The skid detectors and antiskid control shields are tested by using a portable tester designed specifically for this purpose. The tester may be used to bench-test the skid detectors, and it is used to perform a functional test of an antiskid system installed in the aircraft. Functional testing is accomplished by the various controls on the test unit which simulate signals to the control shield. The tester is capable of performing the following test:

- Skid signals from individual detectors.
- Commutator signals from individual detectors.
- Commutator resistance measurements.
- Response of antiskid solenoid valves.
- Complete antiskid control cycle.

1-23. Figure 5 shows the front of a typical antiskid system tester. Let us briefly discuss some of the various parts of the tester. The external power jacks are used to furnish 28 volts dc to the unit when it is used for bench-testing antiskid system units. The ohmmeter jacks (fig. 5) are provided so that an external ohmmeter can be used to measure detector commutator resistance. The "power on" warning light indicates that power has been applied to the tester and the system to be tested.

1-24. Also shown in figure 5 are various warning lights. The lights marked SKID #1 through SKID #4 are used to indicate a skid condition in a detector. The light marked COMM indicates that the detectors are rotating. The light marked S RELAY is illuminated through the control shield when the commutators are rotating. The remaining two warning lights, marked #1 VALVE and #2 VALVE, illuminate when the relative solenoid valve is energized.

1-25. The SKID switch functions to simulate a detector skid signal. The IN FLT - ON GND switch is a three-position switch. In the NEUTRAL position, the switch connects the S RELAY lamp through the control shield. In the IN FLT position, the switch arms the system; while in ON GND position, the switch disarms the system.

1-26. The OHM-OFF switch is used to connect and disconnect power from the circuits to be checked by the external ohmmeter. In the OHM position the circuits do not receive power, and in the OFF position the circuits receive power. The selector switch selects the system circuit to be tested.

1-27. Now that you are familiar with the controls of the tester, let us see how the tester is used to function-test an antiskid system. For this

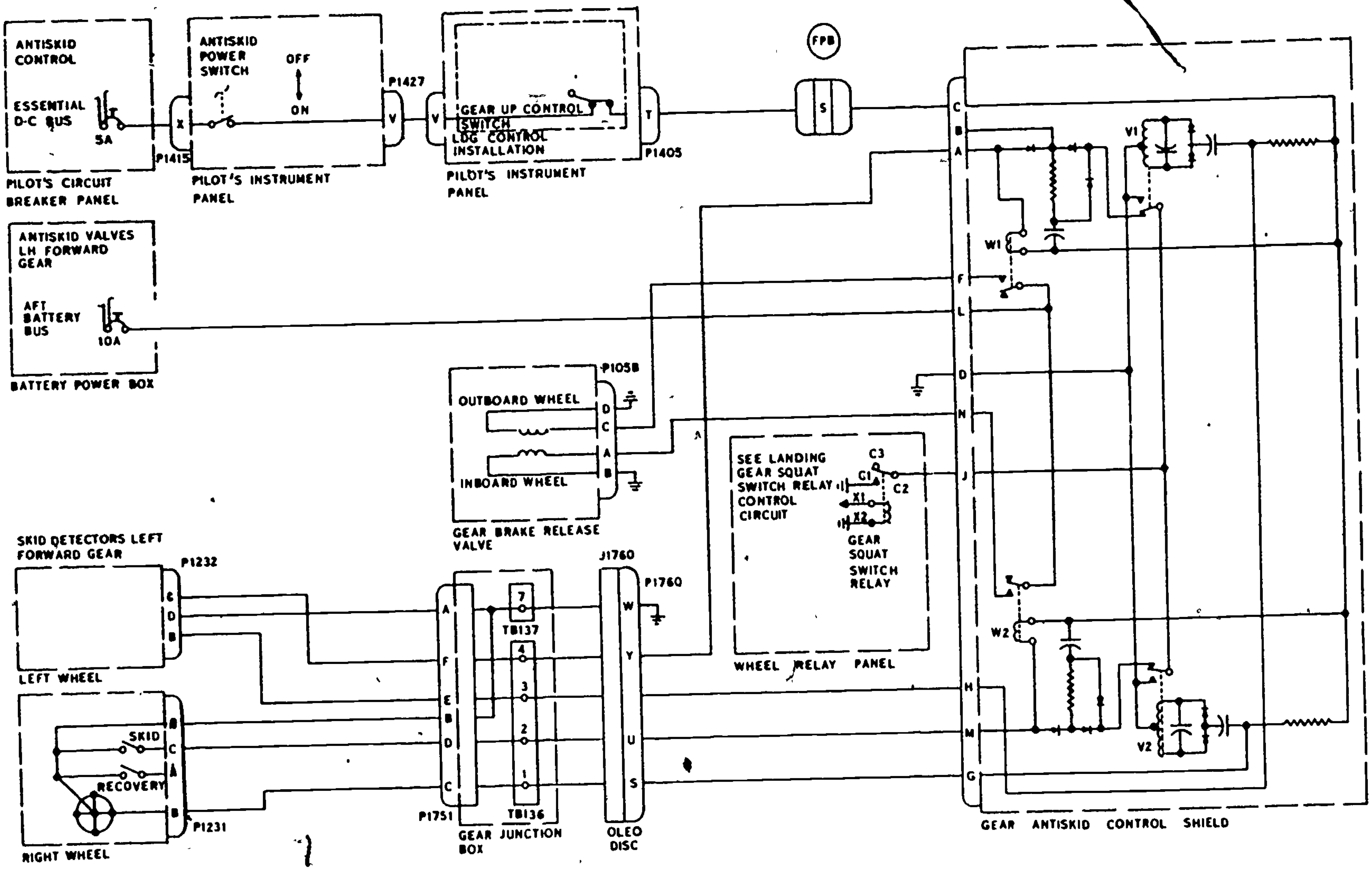

Figure 4. Antiskid circuit.

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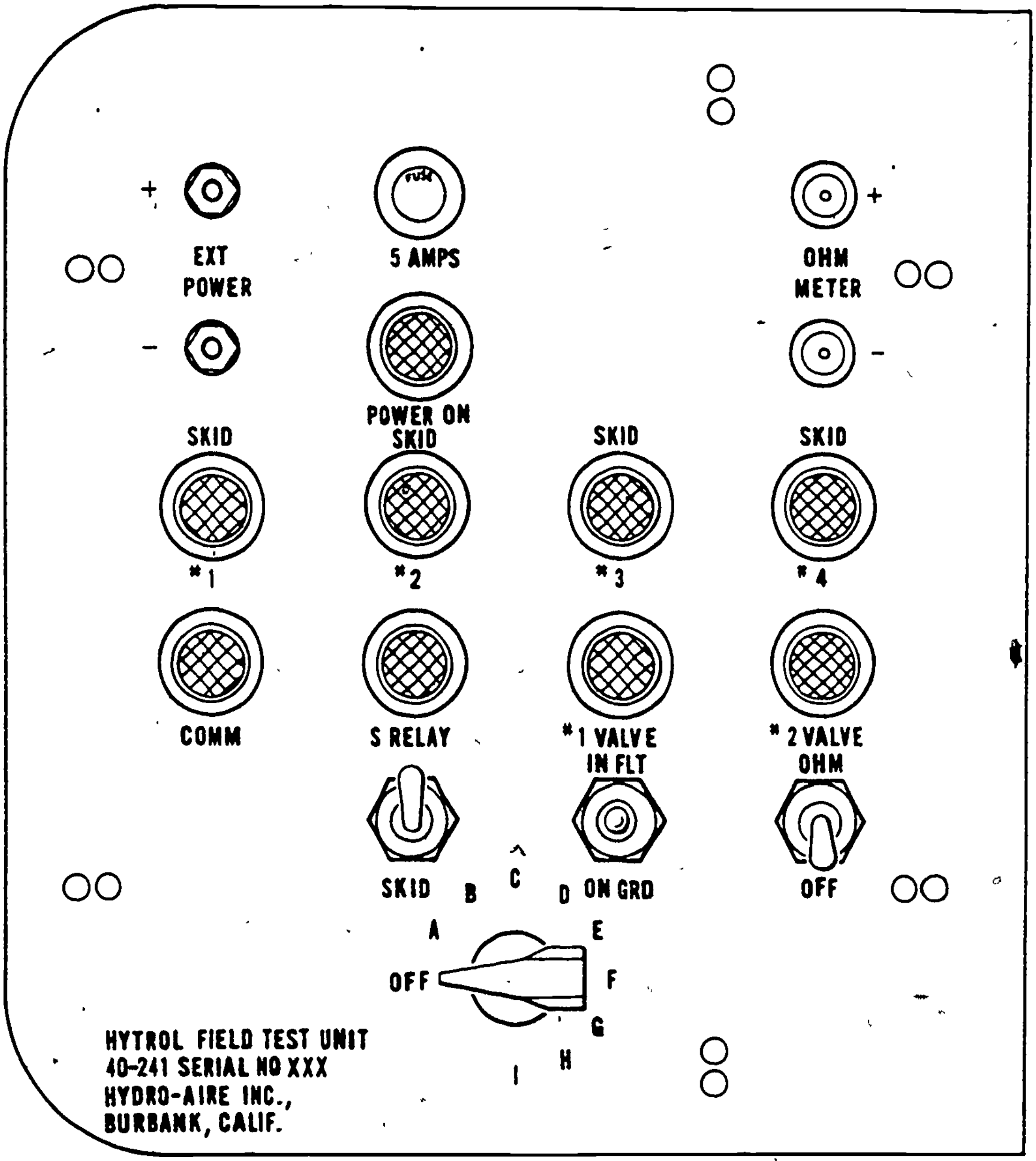

Figure 5. Antiskid system tester.

discussion we will use a system with four detectors: two inboard and two outboard.

1-28. One test that can be made with a tester is a locked wheel test. This is performed with the tester powered from the aircraft. The selector switch is first placed to the OFF position. With the OHM-OFF switch in OFF, and the IN FLT-ON GND switch in the IN FLT position, the Nrs. 1 and 2 valve lamps should be illuminated. This indicates that power is applied to the solenoid valves. If the lamps are not lit, you can assume that the control shield is defective. Now, leaving all the controls in their present positions, rotate the inboard detectors in the normal forward direction of a speed of at least 80 rpm. The #1 VALVE lamp should go dark in approximately 0.5 to 1.0 second. When the detectors coast to a stop, the #1 VALVE should again illuminate and the relative solenoid energize.

1-29. The next part of this test requires that the selector switch be placed to A. The OHM-OFF switch is left at OFF. Now, when the left inboard aft detector is rotated forward at a speed of at least 230 rpm, the COMM light should illuminate. When the selector switch is placed to B and the

other inboard detector is rotated at least 230 rpm, the COMM light should illuminate again.

1-30. The tester can also be used to make a skid test. To do this, the selector switch is moved to E, the OHM-OFF switch to OFF, and the IN FLT-ON GND switch to the ON GND position. When one of the inboard detectors is rotated in a direction opposite to normal to simulate a skid condition, the relative VALVE lamp and SKID lamp should illuminate momentarily. If the lamps do not illuminate, the SKID switch should be held to the SKID position and the detector rotated in a direction opposite to normal. If the lamps do not illuminate, you can suspect a faulty control shield.

1-31. This has been a very brief discussion on the use of the tester. You should realize that the best way to learn the operation of the tester is in your own organization. This discussion has been presented merely to give you an idea as to how a functional test is performed and what is involved.

1-32. This concludes the discussion of a typical heavy aircraft landing gear system. Now, let's discuss a landing gear system such as that found on a typical fighter aircraft.

2. Fighter Aircraft Landing Gear System

2-1. The system selected for this discussion consists of a conventional tricycle type landing gear and a tail skid. The gear and tail skid retract fully into the aircraft and are closed off by doors and fairings. The landing gear, wheel doors, gear and door uplocks, and gear downlocks are actuated by individual hydraulic cylinders. Overcenter locking mechanisms, consisting of arm linkages and mechanical stops, prevent accidental release of various gear and door locks from either the locked or unlocked positions. Strut fairings are actuated by mechanical linkage connected to each of the landing gear struts.

2-2. A combination gear-and-door control valve ports pressure from the hydraulic power system to the actuating cylinders. The control valve is solenoid-operated and is controlled by an electrical sequencing system. Included in the sequencing system are gear uplock, gear downlock, door-closed, and door-open switches. These switches are mounted on the aircraft structure adjacent to the mechanisms by which they are operated. The sequencing system properly cycles the gears and doors after gear-up or gear-down selection is made.

2-3. Load switches and relays are also included in the electrical circuit to insure proper operation of the gear. Individual position indicators, a warning light, and a warning horn in the cockpit provide the pilot with indications of gear position and of safe or unsafe condition. The position indicating and warning system operates electrically through connections with the sequence system switches and throttle.

2-4. The tail skid operates in sequence with the landing gear. It is extended and retracted by an electrical jackscrew type actuator. The landing gear and tail skid shock struts are telescopic units containing specific amounts of hydraulic fluid and air. They absorb the shock loads met during landing. The landing gear wheels are equipped with extra-high-pressure pneumatic tires. The tail skid is equipped with a replaceable steel shoe at the ground-contact surface. The entire landing gear system is normally controlled by a single control handle mounted on the instrument panel.

2-5. Emergency systems are provided to extend or retract the landing gear. Emergency extension of the gear is done mechanically by a system of cables. The cables unlock all gear doors, release the main gear uplocks, override the door and gear control valves, and actuate a nose gear emergency extension control valve. The main gears extend by gravity. The nose gear is hydaulically extended against the airstream by pressure from a nose gear emergency extension accumulator. The entire emergency extension system is operated by a single handle of the instrument panel. An emergency retract button is mounted above the landing gear control handle. Pushing this button with the landing gear control handle in the UP position electrically bypasses the sequencing circuits and load switches. The gear will then retract regardless of the position of the wheel doors.

2-6. **Operation.** A schematic of a typical fighter aircraft landing gear control system is shown in figure 6. The system is shown with the gear down and locked, the gear handle down, the doors closed, and the load switches actuated.

2-7. Normal operation of the landing gear system is divided into two separate cycles: the retraction cycle and the extension cycle. Let us start with the retraction cycle.

2-8. *Retraction.* As shown in figure 6, placing the landing gear control handle to the UP position after takeoff or during a retraction test causes the landing gear unsafe warning light in the landing gear control handle to come on. Placing the landing gear control handle in the UP position initiates the normal retraction cycle. The tail skid is retracted and the wheel doors unlock and open.

2-9. As the first door is unlocked, the landing gear unsafe warning light in the landing gear control handle should come on. The gear downlocks are actuated to unlocked position and the

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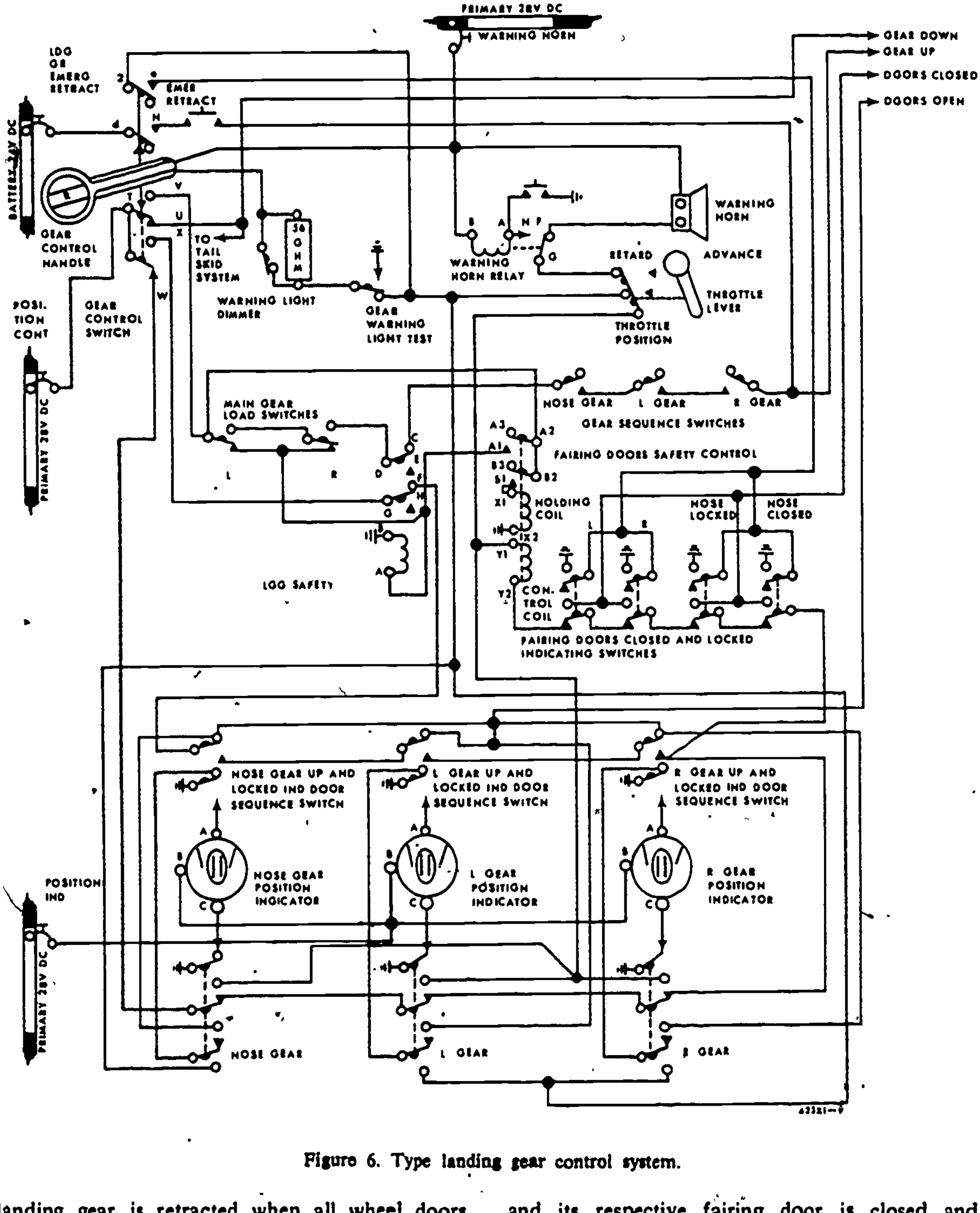

Figure 6. Type landing gear control system.

landing gear is retracted when all wheel doors are full open. As each gear is unlocked, the symbol of the wheel appearing in the same (corresponding) gear position indicator disappears and a "barber pole" appears. When all gears have reached the up-and-locked position, the wheel fairing doors close. As each gear reaches the up-and-locked position, the symbol of a "barber pole" in the same (corresponding) gear position indicator disappears and the word UP appears, to indicate that the gear is up and locked, and its respective fairing door is closed and locked. The landing gear unsafe warning light should go out when all gears are up and locked and all doors are closed and locked while the engine throttle is above 85 percent (± 2 percent) of engine speed. This completes the retraction cycle.

2-10. Table 1 lists the various units in the system and shows when they are operated. Using this table in conjunction with figure 6 will help you learn the detailed operating sequence of

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TABLE 1

LANDING GEAR SYSTEM CONTROL COMPONENTS

Unit	Operation
Main gear load switch	When strut compressed (weight of aircraft on gear)
Nose gear sequence switch	When nose gear fairing door fully open
Main gear sequence switch	When related wheel fairing door fully open
Nose gear up and locked indicating and door sequence switch	When nose gear up and locked
Main gear up and locked indicating and door sequence switch	When related gear up and locked
Nose gear down and locked indicating and door sequence switch	When nose gear down and locked
Main gear down and locked indicating and door sequence switch	When related gear down and locked
Nose gear fairing door closed indicating switch	When door is closed
Nose gear fairing door locked indicating switch	When door is locked closed
Main gear fairing door locked indicating switch	When related door is locked closed
Warning horn relay	When horn cutout relay depressed
Fairing door safety relay	Control coil energizes when all gear up and locked and all doors closed and locked. Holding coil then denergizes the control coil.
Landing safety relay	When gear handle up and struts compressed or when gear handle up, all gear up and all doors closed

this system. With the aircraft weight off the main gear after takeoff, the electrical load switches on each main gear strut are deactuated. This completes the sequencing system circuit, preparing the system for actuation. When the landing gear control handle is moved to the UP position, the gear control switch is actuated and directs current into the sequencing circuit. With the gear in the down-and-locked position and the wheel doors closed, the sequence switches direct current to the door open solenoid of the landing gear and door control valve. When this solenoid is energized, a valve is positioned to direct hydraulic pressure to the door and the door lock actuating cylinders at the same time. The lock cylinders move the overcenter mechanism out of the overcenter position, allowing the hooks to be rotated to the UNLOCK position. This frees the doors, allowing them to be opened by the door-actuating cylinders. Hydraulic pressure is maintained to the door-open and unlocked sides of the actuating cylinders. Each door, upon reaching the full-open position, actuates a sequence switch in the gear-up circuit. When all three doors are fully open, the circuit is completed to energize the gear-up solenoid of the landing gear and door control valve. This makes the valve direct pressure to the up side of the gear actuating cylinders and to the unlock side of the downlock actuating cylinders. The nose gear downlock pin is pulled, and the nose gear uplock hook is positioned to receive the uplock roller on the nose gear. At the same time, the main gear uplocks are in position to lock, and all of the gear actuating cylinders are pressurized to retract the gear.

2-11. As each gear reaches the up-and-locked position, it operates a sequence switch which is connected mechanically to each gear uplock hook. When all three sequence switches are actuated, a circuit is completed to energize the door-closed solenoid and deenergize the door-open solenoid in the landing gear and door control valve. This causes the valve to reverse the hydraulic flow to the door cylinders. Pressure is then directed to the door actuating and lock actuating cylinders to close and lock the doors.

2-12. As the doors leave the full open position, the gear-up solenoid is deenergized, causing

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hydraulic pressure to be removed from the gear actuating cylinders.

2-13. When all three doors are closed and locked, the electrical circuit energizing the door-closed solenoid is broken, the solenoid is deenergized, and the valve shifts to neutral. When the door-closed and gear-up control valves are in neutral, hydraulic pressure is stopped at the landing gear and door control valve. All lines to the door, gear, and lock actuating cylinders are then open to the return lines, and the gear system is depressurized.

2-14. *Extension.* Placing the landing gear control handle to the DOWN position causes the landing gear unsafe warning light to come on and the landing gear warning horn to sound, indicating a landing gear unsafe condition. At the same time, the normal extension cycle is initiated. The tail skid is extended, and all wheel door locks and landing gear locks are actuated to the unlocked position. The doors are opened and the landing gear is extended. Because of a priority valve in the landing gear extend line, the doors are normally opened ahead of the extending landing gear. As each landing gear door unlocks, the word UP disappears in the corresponding gear position indicator, and a "barber pole" appears, indicating that the landing gear door is unlocked. As each landing gear reaches the down-and-locked position, the "barber pole" disappears and a symbol of a wheel appears in the corresponding gear position indicator, as shown in figure 6. When all landing gear is down and locked, the landing gear unsafe warning light goes out and the unsafe warning horn is silent, indicating that the landing gear is safe. At the same time, the landing gear doors are closed and locked to complete the landing gear extension cycle.

2-15. When the landing gear control handle is moved to the DOWN position, the gear control switch directs dc power to the sequencing system.

2-16. With the gear in the UPLOCKED position and the wheel doors closed and locked, the sequence switches are positioned to direct current to the door-open solenoid and the gear down solenoid in the landing gear and door control valve (not shown). As the solenoids are energized, the respective hydraulic control valves are positioned to open the doors and extend the gear.

2-17. When all the gears are down and locked, the sequence switches actuate and send power to the control valves to lock the gear in the DOWN position and close and lock the gear doors.

2-18. **Landing Gear Position and Warning System.** The landing gear position and warning system (shown in fig. 6) consists of the gear position indicators, a warning horn, and a red warning light in the gear control handle. The position indicators are operated by movement of the gear and door mechanisms.

2-19. The single switch that energizes the warning horn is mounted adjacent to, and is operated by, a sector in the throttle linkage. The landing gear position indicators provide the pilot with a visual indication of the gear position. The red warning light and warning horn inform the pilot of various gear or door unsafe conditions. A warning horn cutout button is adjacent to the landing gear control handle. This button is used to silence the horn after the audible warning has been received.

2-20. The warning system red light in the gear control handle goes on when any gear or door is not uplocked with the landing gear control handle in the UP position. (See fig. 6.) The warning horn and the red light are energized if the pilot retards the throttle below the minimum cruise power setting while the gear is retracted. Moving the landing gear control handle to the DOWN position electrically energizes the landing gear and door control valves to position the gears and doors. The light will also come on if the gear handle is moved to the DOWN position when the throttle is retarded.

2-21. The landing gear position indicating system shown in figure 6 is composed of three separate indicating units, one for each main gear and one for the nose gear. The three units are mounted together on a vertical panel on the left side of the pilot's instrument panel. Each unit consists of a pair of coils mounted on a common iron core and a circular dial-and-magnet assembly supported on pivots.

2-22. In operation, only one coil at a time is energized. As a result, the dial is moved around so that either the word UP or a small wheel appears through a window in the indicator. When neither coil is energized, a centering spring pulls the dial-and-magnet assembly to a midway position. A "barber pole" is then shown through the window, denoting that the gear is unsafe. The indicator uses 28 volt dc power for operation. Current is supplied directly to the unit whenever power is on the aircraft. The coils that control the direction in which the dial is moved are energized when the circuit through the position indicating and warning system switches is grounded.

2-23. This concludes the discussion of landing gear circuits. The remainder of this chapter will cover some typical malfunctions you may encounter, as well as a typical adjustment procedure.

2-24. **Circuit Malfunctions.** As an aircraft electrician, you are required to troubleshoot electri-

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cal malfunctions in landing gear circuits. You must be able to combine your skill in troubleshooting with an intimate knowledge of typical landing gear circuits. Unlike many other electrical circuits, landing gear systems require a certain sequence in which the control and warning circuits must operate. For example, in the typical fighter aircraft landing gear circuit, shown in figure 6, the gear doors must open, the landing gear must either extend or retract, then the doors must reclose.

2-25. To give you an idea of some of the more typical malfunctions you may meet in your work, the following examples are provided. Before we begin, however, let us discuss some of the hazards involved in troubleshooting landing gear circuits. Although there is a certain element of danger involved in working on any electrical system, landing gear systems are particularly dangerous because of the speed with which they usually operate. If the gear or the gear door should start to operate while you are working on it, you could be seriously hurt. For this reason, you should never work within a wheel well area when hydraulic pressure or electrical power is applied to the gear. If it is necessary for you to troubleshoot a gear circuit, either remove power or insure that the safety pins are installed in the gear assembly. Now we may turn our attention to some examples of typical landing gear circuit malfunctions, using figure 6 for reference.

2-26. *Example Nr. 1.* For this example assume that during a gear retraction test the gear handle was moved to the UP position and all the gear retracted and the gear doors closed. When the position indicators were checked, however, they showed that the main gears were in an up-and-locked position but that the nose gear was in an intermediate position. By examining figure 6, you can see that all the indicators receive power from the POSITION IND circuit breaker. There are several possible malfunctions that could cause this trouble. Your first check might be at "B" of the indicator to see if dc is available. If dc power is present at "B," check the continuity between "A" of the indicator and ground. If there is continuity, the indicator is faulty and must be replaced. If there is no continuity between "A" of the indicator and ground, it is probable that you have a defective or misadjusted nose gear up-and-locked indicating and door sequence switch. If you manually actuate the switch so that the position indicator shows an up-and-locked condition, this tells you that the switch must be adjusted.

2-27. *Example Nr. 2.* For this malfunction again assume that a retraction test is being performed. When the landing gear control lever is moved to the UP position the gears retract, the doors close, and the position indicators show that all the gears are in the up-and-locked position. When the throttle is advanced, however, the unsafe warning light remains on. As shown in figure 6, if all of the fairing doors are not closed and locked, the ground circuit for the unsafe warning light is completed through any of the fairing doors closed-and-locked indicating switches. The cause of this malfunction could be either an unlocked door or a misadjusted fairing door closed and locked indicating switch.

2-28. *Example Nr. 3.* In this problem the gear doors open, but none of the gears retract. By examining figure 6, you know that the circuit from the gear control switch (T to X) through the deenergized landing safety relay and the nose gear up and locked indicating door sequence switch to the door open circuit must be good because the doors have opened. Using table 1 and figure 6, you know that the circuit to move the gear to the UP position is completed through the main gear load switches, and the deenergized landing safety relay (D to C) and the gear sequence switches. These three units are the most probable causes of the malfunction.

2-29. This concludes the discussion of some typical landing gear system malfunctions. Bear in mind that this section has only touched very briefly on the subject. You will no doubt encounter a wide variety of unusual and different troubles. The systems we have discussed are typical of those you will encounter in your work.

2-30. **Maintenance.** Earlier in this chapter we said that as an aircraft electrician, you are responsible for maintaining the electrical components of landing gear systems. This means that you are required to remove, replace, and adjust the various warning and control units used in these systems. Although it is not the intent of this course to teach you how to do specific jobs, the following discussion will give you an idea of what is involved in adjusting a typical landing gear system component, such as a position switch. Before we start, however, let's briefly discuss some of the safety factors involved in working on any landing gear system component. First, always make sure that the downlock safety pins are correctly installed in the gear assembly and that the landing gear control lever is in the GEAR DOWN position. Next, make sure that all of the circuit breakers for the gear you are working on are pulled. Some of the circuit breakers may have to be reset to furnish power in the adjusting process. It is also a good idea to check the gear position indicators while power is still on the aircraft to insure that they indicate that the gear is in the down-and-locked position. Finally, make sure that you refer to the pertinent technical reference before attempting any maintenance on landing gear

systems. Now we shall learn about the adjustment procedure of a position switch.

2-31. A typical position switch is shown in figure 7. The cover of the position switch box has been removed to expose the setscrew. The locknut on the setscrew should be loosened and the setscrew rotated counterclockwise several times to insure that the position switch is deactuated.

2-32. With hydraulic pressure applied to the gear you are working on, the setscrew should be rotated clockwise until the switch actuates. At this time the gear position indicator for this gear should indicate that the gear is in the down-and-locked position.

2-33. After the position switch has been actuated, continue to rotate the setscrew clockwise a minimum of one complete turn and a maximum of one and one-half turns.

2-34. Next, the actuator blade should be checked for its range of travel. This is done without hydraulic pressure to the gear. The actuator blade should first be moved upward to deactuate the position switch. At this time the gear position indicator should show an intermediate position (barber pole). On some aircraft, additional upward movement of the actuator blade actuates the position switch to a position that causes the gear position indicator to show a gear up-and-locked position. Manually moving the actuator blade downward should actuate the position switch and the gear position indicator should show a gear down-and-locked position.

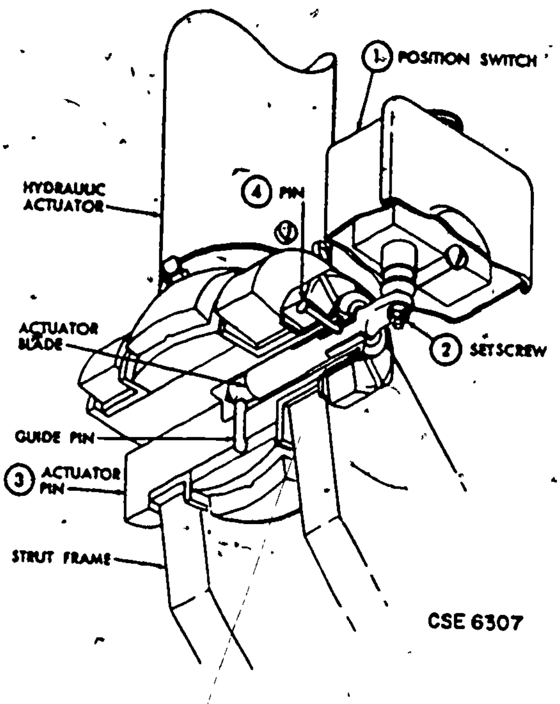

Figure 7. Landing gear position switch.

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Flight Control Electrical Systems

AIRCRAFT FLIGHT control systems control an aircraft in flight. Primary control surfaces, such as the rudder, elevator, ailerons, and flaps, are used to control directional movements. Power to move these surfaces may be supplied by mechanical, hydraulic, electric, or electric-hydraulic means. Most aircraft use the hydraulic system to provide a boost to assist the pilot in the manual operation of the rudder, elevator, and ailerons; electrical power usually operates the flap systems.

2. Sometimes it is necessary to make minor corrections in aircraft attitude during flight because of the changes in the position of the center of gravity or wind direction. This may be done by various trim control systems on the basic surface controls. Sometimes the trim control system involves movement of the entire basic control surface, while on other systems just a small tab on the main control surface is moved. A slight movement of this tab will cause the control surface to which it is attached to be repositioned. We shall devote this chapter to a discussion of the operation and maintenance of trim control circuits.

3. In the first section of this chapter we shall discuss the electrical circuitry pertaining to flap systems. In the remaining two sections we shall cover the circuitry pertaining to trim control circuits.

3. Wing Flap Control Circuits

3-1. For comparison, let's first discuss the flap system on aircraft that has an inboard and an outboard flap section on each wing, then a flap system that has leading edge flaps and trailing edge flaps on each wing. Both flap systems have the same job: to add to the lift of the wing in order to provide for shortened takeoffs and reduced landing speeds.

3-2. **Wing Inboard and Outboard Flap System.** Refer to foldout 1 (This and FO 2–6 are printed and bound in the back of this volume.) for the following discussion of wing flap control circuits. The four flap sections, one inboard and one outboard section on each wing, are driven simultaneously by two motors incorporated into a drive power unit. Attached to the drive power unit is a flap limit switch assembly that contains five adjustable cam-operated "Microswitches"; the right-hand (RH) EXTEND, the left-hand (LH) EXTEND, the RH RETRACT, the LH RETRACT, and the FLAP WARNING SWITCH. The three-phase ac motors are joined together by a differential gearing. Both motors usually operate together; however, the differential gears in the drive unit permit the operation of the flap system by either motor in case of a motor failure.

3-3. The control of the wing flap drive system can be provided by two separate dc-powered control circuits. One circuit controls only the right motor and the other controls the left motor. The wing flap control circuits originate at the FLAP CONTROL LEVER. This lever provides OFF-UP-DOWN positions with detents at the UP and DOWN positions, and it mechanically buses the two control circuits together. The control lever must be lifted to clear the detent before it can be moved away from any of these positions. When the FLAP CONTROL LEVER is placed in the DOWN position, both motors in the power unit are energized and the flaps are extended. Placing the control lever in the UP position energizes the same motors and retracts the flaps. Extension or retraction may be stopped or reversed at any point in the cycle. The limit switches provide protection for both the UP and DOWN positions.

3-4. A dc relay controls each of the two motors (left and right) in the drive power unit. Each of these relays contains two operating coils with the contacts wired so as to reverse the phase connections to the three-phase motors and thus control the direction of rotation of the flap motors.

3-5. Thus, the components for controlling the flap motor consist of circuit breakers, the flap control lever, two control relays, and an EXTEND LIMIT SWITCH and a RETRACT LIMIT SWITCH through which the control relays are energized.

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In addition, each motor has an internal brake. The brake is spring-actuated to hold the flaps in a fixed position when the motor is not operating. The motors contain a dc power-operated brake solenoid which is energized to release the brake when a torque switch inside the rotor senses sufficient motor torque and actuates the brake release "Microswitch."

3-6. As previously mentioned, the flap control lever operates four "Microswitches": two for the extend circuit and two for the retract circuit. Interruption of the control power through opening of the EXTEND LIMIT SWITCH or the returning of the flap control lever to the OFF position will simultaneously open the control relays and the brake circuit, causing the motor brakes to be applied to maintain any desired flap position.

3-7. Whenever the aircraft is on the ground, the FLAP WARNING SWITCH works in conjunction with the throttle control, the LANDING GEAR SQUAT SWITCH, and the FLAP POSITION WARNING RELAY. Thus, the warning horn will sound whenever the flaps are not fully extended and either number 3 and number 5 throttles or number 4 and number 6 throttles are advanced beyond a preset point above the IDLE position (see FO 1). This warning system uses the same warning horn as the landing gear warning system. But, unlike the landing gear warning horn circuit, it cannot be shut off by a cutoff switch.

3-8. To increase the reliability of this flap system, it has two separate control circuits so that if one fails the other will still function. However, if one motor fails there is a 50-percent reduction in the flap operating speed.

3-9. Supersonic aircraft use a trailing-edge and a leading-edge type of wing flap system. This system is our next topic.

3-10. **Leading-Edge and Trailing-Edge Wing Flaps.** These flaps are electrically interconnected by a control circuit and mechanically interconnected by flexible drive shafts. A set of switches actuated by a single lever in the cockpit controls the flaps. The leading-edge flap control circuit components are shown on foldout 2 and consist of a flap actuator, a flap power relay, an H-BOX, a flap control switch, circuit breakers and a flap lock motor assembly. The leading-edge flap control circuit has a flap lock motor assembly; otherwise, the components of this circuit and of the trailing edge are the same. Since both control circuits are identical, we shall discuss only one—that is, the leading-edge flap control circuit. Keep in mind that both sets of wing flaps are used for takeoffs and landings.

3-11. **Operation of Leading-Edge Flap Control Circuit.** When the flap control is placed in the TAKEOFF (T.O.) position, dc power is applied through the WING FLAP CONTROL SWITCH to the closed contacts of the energized FLAP CONTROL BUS TRANSFER RELAY, and then to the LEADING EDGE FLAP TAKEOFF CONTROL RELAY, as illustrated on foldout 2. The TAKEOFF CONTROL RELAY energizes and dc power is then connected through the RETRACT LIMIT SWITCH of the left leading-edge flap lock actuator motor to the UNLOCKED FIELD of the motor. The motor then begins to operate the jackscrews. (These jackscrews do not move the flaps.) The retraction of the jackscrews pulls the cables to the flap lock assemblies, disengaging the locking hooks and arming (closing) the LEFT and RIGHT FLAP LOCK CONTROL SWITCHES.

3-12. When the actuator jackscrews reach the fully retracted position, the motor RETRACT LIMIT SWITCH opens the motor circuit and the FLAP LOCK MOTOR stops rotating. Also, the motor RETRACT LIMIT SWITCH places dc power through the contacts (unlock position) of the FLAP LOCK CONTROL SWITCHES and through the contacts of the TAKEOFF CONTROL RELAY to the TAKEOFF LIMIT SWITCH (DN) in the H-BOX. The dc power from the DOWN LIMIT SWITCH energizes the MAGNETIC BRAKE inside the H-BOX. The magnetic brake then releases the flap actuator jackscrews (not those operated by the flap lock motor). At the same time, dc power from the DOWN LIMIT SWITCH energizes the LEADING-EDGE FLAP POWER DN RELAY.

3-13. The FLAP POWER DN RELAY completes the ac power circuit to the LEFT and RIGHT LEADING-EDGE FLAP ACTUATORS. The magnetic clutches in both actuators energize (engage), and the flaps move toward the TAKEOFF position. The actuators operate the flexible drive shafts which rotate the shaft and cam mechanism inside the H-BOX.

3-14. When the flaps reach approximately 13° down from the faired (retracted) position, the DOWN LIMIT SWITCH in the H-BOX opens and flaps are stopped. Also the magnetic brake is engaged, and the magnetic clutch in each actuator is disengaged when dc power is removed by the DOWN LIMIT SWITCH. This permits the brake in the H-BOX to stop flap travel through the jackscrews and the actuator motors coast to a stop.

3-15. The selection of LAND (on some aircraft this is called DOWN) position of the FLAP CONTROL SWITCH again energizes the DN power relay and actuators. This time the flap travel is limited by the DOWN LIMIT SWITCH in the H-BOX. The flaps are stopped approximately 28° down from the faired position.

3-16. The selection of T.O position by the FLAP CONTROL SWITCH energizes the UP power relay and the actuators. The phase rotations are

reversed in the motors by the UP power relay when the FLAP CONTROL SWITCH is moved from the LAND position (see FO 2). The flaps retract until stopped by the UP TAKEOFF LIMIT SWITCH in the H-BOX. In this case, the flaps are approximately 13° down from the faired position.

3-17. The selection of UP position by the FLAP CONTROL SWITCH again energizes the UP power relay and the actuators. Now, the flap travel is limited by the UP LIMIT SWITCH in the H-BOX. The flaps are stopped at the faired position.

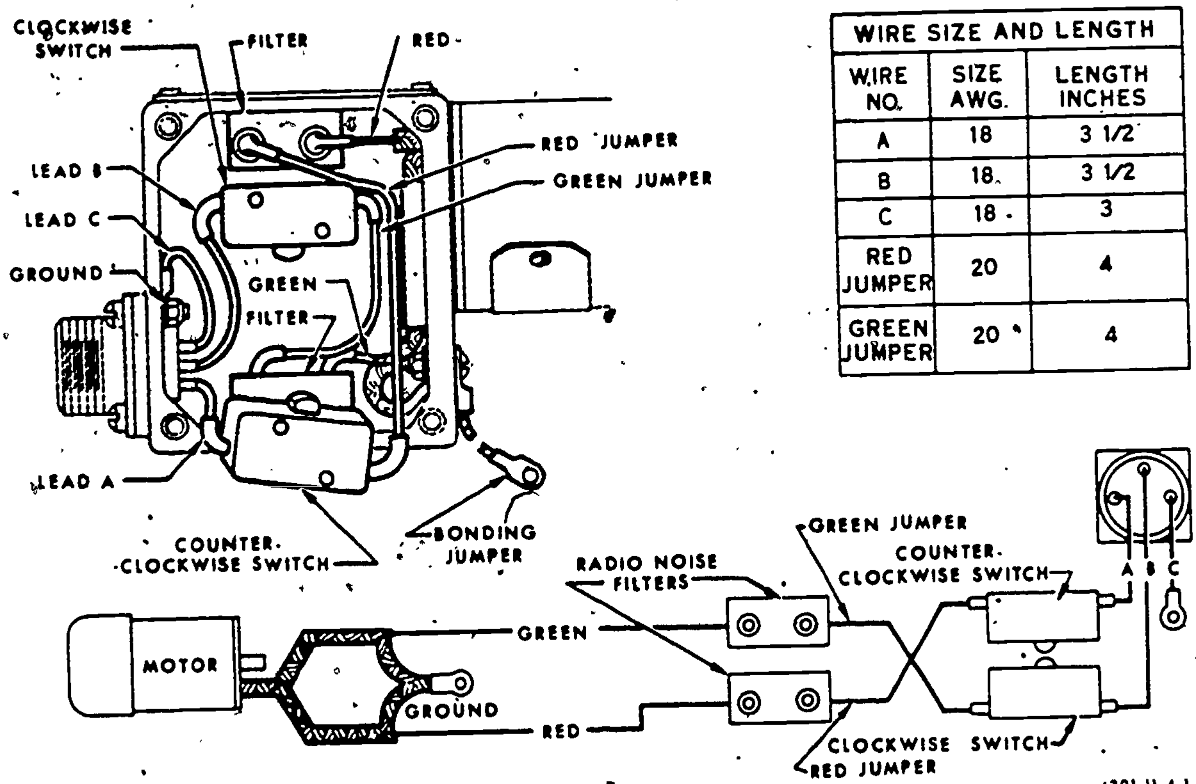
3-18. So far we have mentioned the function of the actuators in these control circuits. Let's stop for a moment and briefly discuss the maintenance of an actuator.

3-19. **Maintenance of an Actuator.** As you know, an actuator is composed of a motor connected to a gear train that drives a flexible shaft. The motor may be controlled manually or automatically by limit switches. The type of motor determines the capability of the actuator.

3-20. Many repair parts for actuators are provided in the form of kits. The stock numbers for the repair kits and for the nonkitted parts may be found in S-00-1-1, Master Cross-Reference Index. The presence of a new part in a repair kit usually eliminates the necessity of cleaning, inspecting or reworking the equivalent part removed from the assembly which is being repaired. If any part in the kit is to be inspected or tested before installation, instructions for performing these requirements are included. When a part is not normally removed in the process of disassembly, and it is serviceable, the part need not be removed solely for the purpose of replacement by a corresponding kitted part. It is important that the applicable technical order for overhaul instructions of an actuator be read and that the instructions be followed carefully. Disassembly and reassembly of actuators should not be performed without the applicable technical order.

3-21. Cleaning consists of washing all nonelectrical parts in an approved cleaning solvent. This should be done in a ventilated area; otherwise personnel may breathe the fumes, which may be toxic. Solvents should not be used in the presence of a fire, since some fumes are flammable.

3-22. The wiring diagram of a typical actuator is illustrated in figure 8. Notice how the wires are placed and connected to each electrical terminal and component. The chart shown in figure 8 lists the size and length of each wire segment inside the actuator. The colored insulation of the wire aids in identifying the wire installed with the wiring on the diagram.



WIRE SIZE AND LENGTH		
WIRE NO.	SIZE AWG.	LENGTH INCHES
A	18	3 1/2
B	18	3 1/2
C	18	3
RED JUMPER	20	4
GREEN JUMPER	20	4

Figure 8. Cutaway-electrical actuator.

3-23. The limit switches may require calibration or adjustment before the actuator is tested for serviceability. In some cases, the limit switches are set when the actuator is installed on the unit it operates. During a no-load test, the actuator should operate in a satisfactory manner—for example, without unusual noise, without binding, and without vibration. During a rated-load test, and load current should not exceed its limits. This concludes our discussion of wing flap control circuits; we shall now turn to the stabilizer trim-control circuit on the airplane.

4. Stabilizer Trim Control Circuit

4-1. In this section, we shall cover the electrical circuitry involved in the operation of the horizontal stabilizer control system. The complete system is shown in foldout 3; you should refer to it during this discussion.

4-2. **System Operation.** The stabilizer is moved to trim the aircraft by a jackscrew that is driven hydraulically. However, the hydraulic system is controlled by any one of three means. The normal control is by an electrical circuit, through switches on the pilot's and copilot's control wheel. The trim control wheel provides a manual means of control, and the automatic pilot provides the third method of control. The method of control that is used is determined by the STABILIZER TRIM CUTOUT SWITCH. This switch is marked NORM and CUTOUT and is shown in the NORM position in foldout 3.

4-3. When the switch is in the NORM position, the system is controlled by the electrical control circuit. Placing the switch in the CUTOUT position transfers system control to the autopilot system. The manual control can be used in conjunction with either system; it is controlled by the trim control wheel.

4-4. The STABILIZER TRIM SWITCHES are powered by 28 volt dc from the circuit breaker shown on the foldout just below the STABILIZER TRIM CUTOUT SWITCH. When either of the stabilizer trim switches is moved to the NOSE DOWN position, current flows through the lower contacts of the TRIM CUTOUT SWITCH, on through the upper contacts of the AUTOPILOT MANUAL STABILIZER TRIM OVERRIDE RELAY, and on to the STABILIZER TRIM CONTROL DOWN RELAY. The current does two things at this point: it flows on to energize the CLUTCH and also energizes the DN RELAY. When the DN RELAY is energized, the triple set of contacts associated with it closes, and three-phase power flows through these contacts to the three-phase motor. Since the clutch was already energized, the motor will turn the DRIVEN FOLLOWUP JACKSCREW and its associated mechanism. The gearing at the upper end of this jackscrew turns an intermediate gear which turns the FIXED FOLLOWUP JACKSCREW. Both jackscrew actions cause the connecting linkage to position a hydraulic metering valve and thereby allow the hydraulic pressure to drive the hydraulic motors. These motors move the STABILIZER JACKSCREW and thus move the stabilizer in a manner to trim the aircraft by causing its nose to go down.

4-5. The only difference in operation when the STABILIZER TRIM SWITCH is placed in the NOSE-UP position is that dc power is applied to the opposite clutch winding. This clutch action causes the DRIVEN FOLLOWUP JACKSCREW to turn in the opposite direction, even though the three-phase motor continues to turn in the same direction. Of course, with the jackscrews turning in the opposite direction, the linkage positions the metering valves in the opposite direction and the hydraulic motors turn the STABILIZER JACKSCREW in the opposite direction to cause a nose-up altitude.

4-6. Brakes are installed on the output shafts of the hydraulic motors. These brakes are engaged to keep the stabilizer from "creeping" or changing its trimmed position after the hydraulic motors stop.

4-7. **Operational Checkouts.** Let's begin by placing the STABILIZER TRIM CUTOUT SWITCH in the NORM position, as illustrated in foldout 3. The proper movement of the stabilizer is checked by moving the trim switch to the NOSE-UP position to trim for a short distance from the 0° position. The stabilizer leading edge should be in the 0° position, as indicated by the decal on the side of the fuselage. The stabilizer leading edge should move down, and the trim indicator should show the correct movement. This is accomplished when the NOSE-UP TRIM SWITCH is depressed, and dc power is applied through the trim switch, and through the NORM position of the TRIM CUTOUT SWITCH. From there, the dc power goes through a set of contacts on the TRIM OVERRIDE RELAY, to the TRIM CONTROL UP RELAY, and to a clutch within the clutch unit. The jackscrew should rotate when the TRIM CONTROL UP RELAY energizes and three-phase ac power is connected to the actuator's motor. Also, when the trim switch is moved to the NOSE DOWN position, the stabilizer leading edge should move up and the trim indicator should show the correct movement.

4-8. Next, let's test to determine if the cutout circuits are in operation. This test is performed with the TRIM CONTROL WHEEL in the 0° position and the STABILIZER TRIM CUTOUT SWITCH in the CUTOUT position. Neither the stabilizer nor the manual trim wheel should move when the trim switch is moved to the NOSE-UP or NOSE-

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DOWN position. This concludes the operational checkout. Two other features of this system that should be mentioned are the stabilizer trim heater circuit and the brakes.

4-9. **Trim Heater Circuit.** If you look at foldout 3, you can see the heating circuitry that keeps the DRIVEN FOLLOWUP and FIXED FOLLOWUP JACKSCREWS heated to prevent icing. These heating elements are of the rod type and are housed inside the jackscrews.

4-10. **Operational Checkout.** The STABILIZER NUT THERMOSTAT is a hermetically sealed unit containing control and overheat thermal switches. A 115-volt test lamp is used to check the operation of this unit. This test lamp is connected between the STABILIZER NUT THERMOSTAT and ground before ac power is applied to the aircraft. The test lamp should illuminate and the followup screws should heat when the STABILIZER TRIM HEATER circuit breaker is closed. After a short heating period, the control switch should open and the test lamp should go out. The temperature range of the stabilizer trim heater may be checked by referring to the applicable technical order. For example, the control switch may close below 45° to 55° F. and open at 55° to 75° F., with an overheat switch set to open at 80° to 90° F. When the temperature of the STABILIZER NUT THERMOSTAT is above the operating range of the control switch, the test lamp should not be illuminated and the control switch should be opened.

4-11. The overheat switch may be checked by placing a jumper wire across the terminals of the stabilizer nut thermostat. The test lamp should come on and the follow-up screws should heat when the stabilizer trim heater circuit breaker is reset. After a short period of heating, the overheat switch should open and the test lamp should go out. To prevent possible personal injury and equipment damage, the electrical power is turned off before the jumper wire and the test lamp are removed. This concludes our discussion of the stabilizer trim control circuit. We shall now consider another important flight control circuit, the aileron trim control.

5. Aileron Trim Control Circuit

5-1. The ailerons control the movement of an aircraft about its longitudinal axis. Moving the control wheel, or stick, to lower the aileron on one wing raises the aileron on the other wing. The aileron trim control circuit is provided to assist the pilot in maintaining the level flight attitude of the airplane. Foldout 4 illustrates the aileron trim control circuit which will be used during the following explanation. Let's begin by discussing the operation; later we shall discuss the operational checkout.

5-2. **System Operation.** The aileron trib tabs are positioned by the aileron trim actuators. These actuators are driven by the trim motor through flexible drive shafts. However, the left and right trim actuators and tabs move in opposite directions. That is, as the left tab moves *up*, the right tab travels *down* the same distance. Since these tabs operate in opposite directions, they jointly aid in rolling the aircraft around its longitudinal axis.

5-3. When the TRIM SELECTOR SWITCH is placed in the STICK TRIM position, power is applied to the STICK TRIM LOCKOUT RELAY. When this relay is energized, the trim system cannot be operated since the electrical circuit to the CONTROL STICK TRIM SWITCH is open. This prevents operation of the system when the hydraulic system has failed. Let's assume that hydraulic pressure is normal. Under this condition the relay contacts will be as shown and power is applied to the CONTROL STICK TRIM SWITCH. Actuation of this switch will direct power to the trim motor.

5-4. Should the aircraft require a right wing down condition to maintain level attitude, the pilot actuates the CONTROL STICK TRIM SWITCH to the R WING DOWN (L WING UP) position. This directs power to the lower limit switch of the trim motor, and the FIELD, ARM, and MAGNETIC BRAKE are energized. The motor will continue to run until the CONTROL STICK TRIM SWITCH is released or the trim motor reaches its limits and the limit switch opens.

5-5. Regardless of the degree of aileron deflection, the control stick position will be the same as it was when the trim was initiated. Toggling the thumb-actuated control stick grip trim switch to the left will produce exactly the same operation, but in the opposite direction.

5-6. With the aircraft on the ground, the electrical system energized, and the hydraulic systems under pressure, the takeoff trim indicator lights may be energized either through the TAKEOFF TRIM IND SWITCH in the trim motor or by the WARN LT TEST switch.

5-7. Normal operation through the motor switch occurs whenever the trim motor is run to the takeoff trim position of the ailerons and the trim control is actuated. The indicator will not remain on after the trim control switch is released. To establish the takeoff trim position of the ailerons, select either left or right trim with the control stick grip trim switch and hold it until the trim indicator light momentarily flashes on, then off. Immediately release the switch, then

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toggle it for the opposite trim, but in small increments, until the indicator light flashes on. Immediately release the switch, and the ailerons will be in the takeoff trim position.

5-8. To test the takeoff trim indicator lights, select the WARN LT TEST position of the test switch. This provides an alternate source of power from the dc emergency bus, energizing a WARNING LIGHT RELAY which directs power to the takeoff trim indicator lights. The ground side of the lights then passes through the energized GROUND-AIR SAFETY RELAY contacts when the aircraft is on the ground and electrical power is on, then to ground through the WARNING LIGHT RELAY NO. 2 switch contacts.

5-9. The lights cannot operate once the aircraft is airborne because of the landing-gear-actuated ground-air safety switch. This prevents the lights from disturbing the pilot's vision when inflight trim of the aircraft is required With the above circuits in mind, let us discuss the operational checkout.

5-10. **Operational Checkout.** Certain precautions should be observed during this operational check. The aileron trim system should not be operated unless power is supplied to *both* the electrical and hydraulic systems because otherwise damage may result to the trim actuator motor and the flex shaft. Before turning on the ground power supply, all the switches and controls should be checked and moved to the GROUND position, and all the control surfaces should be clear of obstructions. You should read and understand all of the various *cautions* and *notes* necessary for this system operation in the applicable technical order.

5-11. With all the preparations completed, and the power supplies connected, the aileron takeoff trim indicator lights should not be illuminated if the control stick is in the neutral position. When the maximum aileron travel is obtained by holding the control stick trim control switch, the aileron takeoff trim indicator lights should flash. The maximum aileron travel and flashing of the aileron takeoff trim indicator lights should be checked for movement in both directions. The left aileron and right aileron should travel so many degrees, one up and the other down, and adjustment should be made if the travel of each is out of tolerance according to the applicable technical order.

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Warning Circuits

THE WARNING systems inform the crew whether or not the aircraft is in a safe condition for takeoff, normal operation, or landing. Since no one can accurately predict when a particular piece of equipment is going to fail, warning systems are installed as a precaution. However, warning systems are not designed solely for emergencies. They may serve as a check on components that are located out of sight of the flight crew; they also tell the crew of operating conditions that require some adjustment. The warning unit may be a light, a bell, or a horn. Warning devices are usually controlled through switches which may be operated by pressure, temperature, or a mechanical linkage. Sometimes the switches are connected in parallel or series-parallel to enable the operating personnel to know the operating conditions of individual portions of the complete circuit.

2. Fire is one of the most dangerous conditions on board an aircraft, so the first part of this discussion will be concerned with the various types of fire warning systems.

6. Fire and Overheat Warning

6-1. In order to detect fires or overheat conditions, detectors are placed in the various zones to be monitored, usually the engine and baggage compartments of the more conventional types of aircraft or the engine section, nacelle, or tail cone of jet type aircraft. There are four types of fire detectors currently in use: the thermal switch, the thermocouple, the photoelectric type, and the continuous cable.

6-2. **Thermal Switch Circuit.** The thermal switch type of warning system consists of one or more lights energized from the installation's power supply system and a number of thermal switches that control operation of the light(s). These thermal switches are heat-sensitive units that complete an electric circuit when they are exposed to a certain temperature. These thermal switches are connected in parallel with each other but in series with the warning light, as shown in figure 9. Whenever the heat rises above a certain value in any one section of the installation where the thermal switches are located, the overtemperature or fire warning light is illuminated by the closing of the thermal switch. Thus, the thermal switch completes a ground path for current flow. There is no set number of switches required: the exact number being determined by the aircraft.

6-3. *Thermal switches.* The Fenwal switch is constructed with two silver contacts mounted on, but electrically insulated from, curved nickel-iron struts having a low expansion coefficient. See figure 10 for the details of construction of the Fenwal switch. The contact assembly is mounted in a seamless drawn brass or stainless steel tube that has a high coefficient of expansion.

6-4. The Iron Fireman switch is constructed with a high-nickel steel rod located along the centerline of the tube, with one end of the rod attached to the opposite end of the tube from the mounting flange, as shown by the cross-sectional view of the construction shown in figure 11. The other end of the nickel steel rod presses against a switch blade so that it holds a pair of electrical contacts in an open position. This assembly is mounted in a ventilated stainless steel tube that has a high coefficient of expansion.

6-5. When these switches are subjected to heat, both the shell and the internal elements will expand and a subsequent increase in overall length will result. However, the relative increase in the length of the shell, having a high coefficient of expansion, will be much greater than that of the internal elements assembly. The temperature at which the shell expands lengthwise sufficiently to allow the switch contacts to close is considered the actuating point.

6-6. The maximum tolerances from the actuating point of the fire detector switches which are acceptable are as follows: For switches operating below 300° F., the tolerance should be plus or minus 15° F.; for switches operating above 300° F., the tolerance should be plus or minus 25° F.

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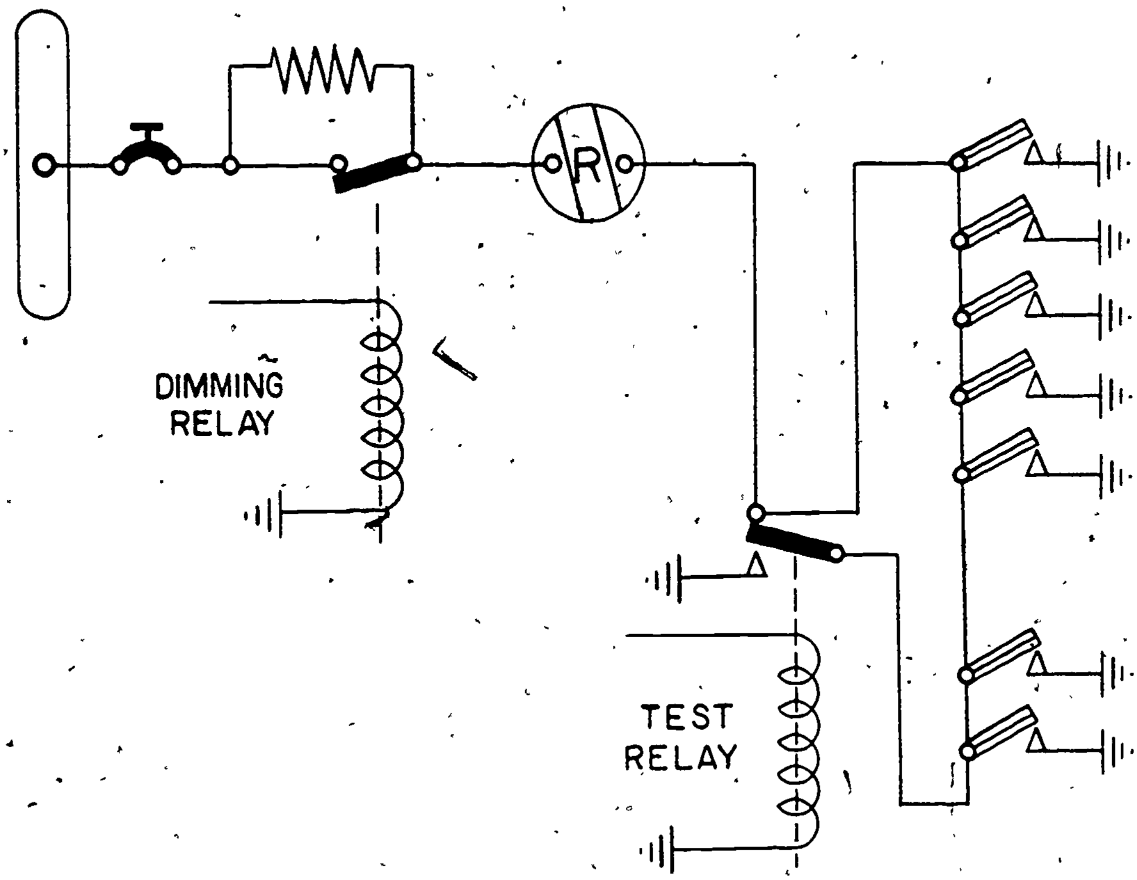

Figure 9. Thermal switch circuit.

6-7. Caution must be observed when handling these units because the shell is the actuating mechanism. The shell should never be handled with pliers or forced into position either by hand or with tools. Before, during, and after installation, precautionary measures must be taken to insure that the shell is not dented, distorted, or otherwise damaged. In addition, caution must be exercised in securing the lockwasher and hex nut on the positive terminal of the switch. When securing the terminal nut, a torque wrench must be used. A maximum of 20 inch-pounds torque can be applied to this terminal when the insert is constructed of alumina (porcelain) material. Ter-

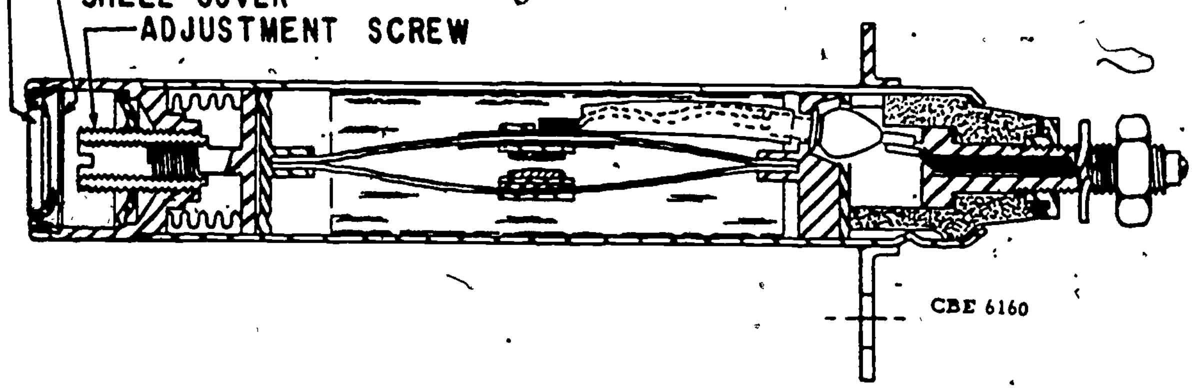

Figure 10. Fenwal thermal switch.

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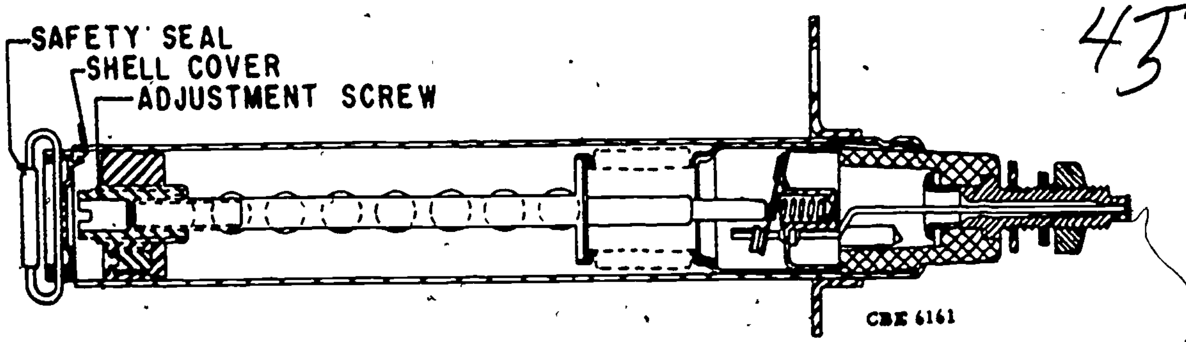


Figure 11. Iron Fireman thermal switch.

minals with inserts of Fiberglas material will withstand only 15 inch-pounds torque.

6-8. Upon installation of a new switch, the outer shell could be visually inspected for evidence of any damage which could change the actuating point or prevent the switch from operating. After the switch has been put into operation, it should always be kept free of dirt, dust, oil, grease, or any foreign substance which may accumulate on the switch and change the amount of heat required to actuate the switch.

6-9. The thermal switches have different heat ranges, so that they may be used in different locations in the engine area.

6-10. The heat range for a Type E–2 detector switch, for example, is 300° F. to 750° F., whereas the range for a Type E–4 is from 100° F. to 1,000° F. The type number of the detector switch can be located on the unit's mounting flange.

6-11. *Thermal switch testing.* Fire and overheat detector switches may be adjusted, by operating personnel, to any desired temperature within the unit's range by using one of the several different models of calibrators and/or testers available through normal Air Force Supply channels. The following described procedures are based on the use of the Fenwal high-temperature test kit, which is a portable testing device designed to provide convenient facilities for adjusting or checking the temperature setting of thermal switches. The high-temperature test kit consists of the test stand, a metal case, and a group of accessories, such as can be seen by referring to figure 12. The test stand includes the base, the supporting aluminum rod, the control panel, and the test block.

6-12. The test block is designed to provide true THERMOSWITCH temperature settings for units mounted from the top of the test block using the special thermocouple assembly provided to measure temperatures. For convenience, a thermometer is also supplied with this kit and provisions have been made for inserting flange (aircraft) THERMOSWITCH units from the bottom of the test block. The maximum test block exposure temperatures are 1,200° F. for a 5-minute period or 1,000° F. for 500 hours of operation. The test block may be exposed to these temperatures continuously for the specified period without detrimental effects.

6-13. Operating temperatures within the range of 800° F. to 1,000° F. may be obtained by operating the test unit directly on 115 volts ac. Approximately 20 minutes will be required for the test block to reach 1,000° F. when starting from room temperatures.

6-14. Operating temperatures in the range of 100° F. to 800° F. may be obtained by using a

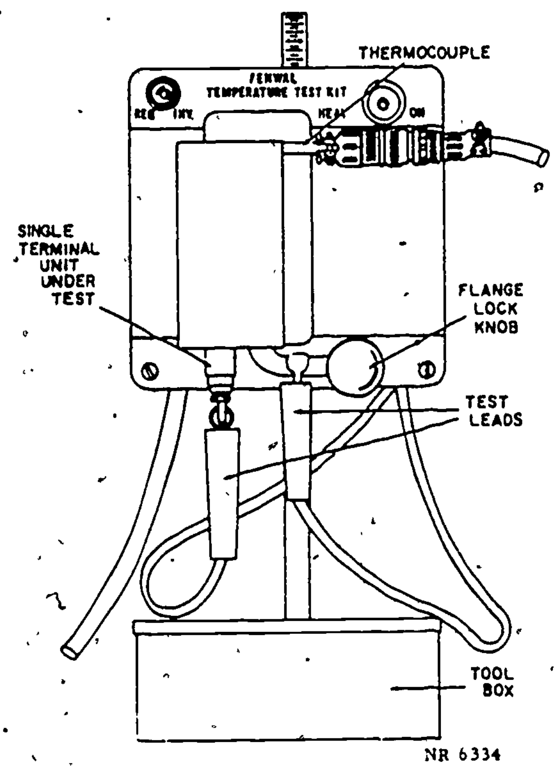


Figure 12. Test kit with detector inserted from bottom.

115-volt variable voltage transformer having a 115-volt, 500-watt output. The heating time in this case is dependent on input voltage and the temperature desired.

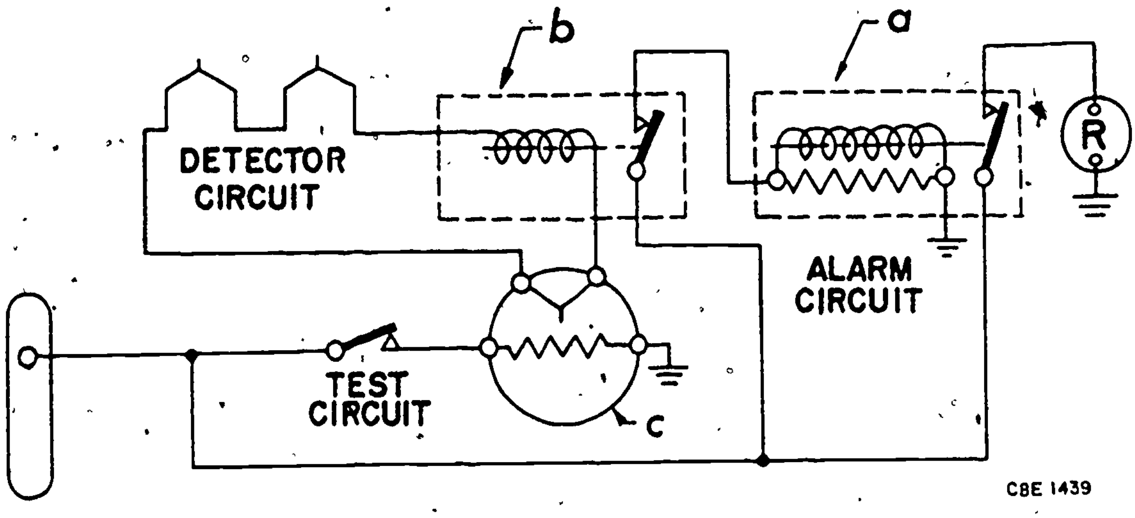
6-15. When the THERMOSWITCH unit has been adjusted to room temperature (approximately 70° F.) an approximate temperature setting can be obtained by rotating the adjusting sleeve the proper number of turns for the given unit. The approximate temperature adjustment rate of THERMOSWITCH units can be determined from the applicable technical order.

6-16. **Thermocouple Fire Warning Circuit.** The thermocouple fire warning system operates on an entirely different principle than does the thermal switch type. A thermocouple depends upon the rate of temperature rise and will not give a warning when an engine slowly overheats or a short circuit develops. The system is composed of a relay box, warning lights, and the thermocouples. The wiring of these units can be divided into three circuits: the detector, the alarm, and the test circuit, as shown in figure 13.

6-17. *Components.* The relay box contains two relays: the sensitive relay (item b) and the slave relay (item a), as well as the thermal test unit (item c) in figure 13. Such a box may contain from one to eight identical circuits, depending on the number of potential fire zones. For example, a four-engine aircraft may use two relay boxes, each of which contains six identical circuits. This aircraft may need twelve circuits if each engine has three potential fire zones. The warning lights are controlled by the relays. In turn, the operation of the relays is regulated by the thermocouples distributed in the potential fire zones. The fire detector circuit consists of several thermocouples connected in series to each other and with the sensitive relay coil. Figure 14 shows a sectionalized view of a typical thermocouple. This device is constructed of two different metals: chromel and constantan. At the point where these metals are joined and will be exposed to the heat of a fire, we have what is called a *hot junction.* The thermocouple also has a *reference junction* inclosed in a dead airspace between two insulation blocks. Finally, there is a metal cage to provide mechanical protection for the thermocouple without hindering the free movement of air to the hot junction.

6-18. As the temperature rises rapidly, the thermocouple produces a voltage because of the temperature difference between the *hot junction* and the *reference junction.* If both junctions are heated at the same rate, no voltage will result. In the engine compartment there is a normal gradual rise in temperature from engine operation; because it is gradual, both junctions heat at the same rate and no warning signal is given. If there is a fire, however, the hot junctions will heat more rapidly than the reference one. The resulting voltage causes a current to flow within the detector circuit. At any time the current exceeds 4 milliamperes (0.004 ampere), the sensitive relay, shown in figure 13, will close and complete a circuit between the aircraft power system and the coil of the slave relay. The slave relay then closes and completes the circuit to the warning light, as shown in figure 13. The light flashes on and gives a visual indication of fire.

6-19. As previously mentioned, the total number of thermocouples used in individual detector



a. Slave relay   b. Sensitive relay   c. Thermal test unit

Figure 13. Thermocouple fire warning circuit.

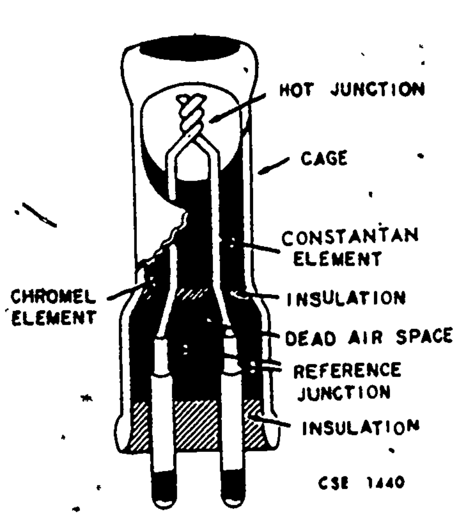


Figure 14. Typical thermocouple.

circuits depends on the size of the potential fire zone and the total circuit resistance. The circuit resistance should never exceed 5 ohms. As shown in figure 13, the circuit has two resistors. The resistor connected across the terminals of the slave relay absorbs the coil's self-induced voltage. This arrangement is for the purpose of preventing arcing across the contacts of the sensitive relay; these contacts are so fragile that they would burn or weld together if arcing were permitted. This is how the elimination process works. When the sensitive relay opens (fig. 13), it interrupts the electric circuit to the slave relay and causes the magnetic field which is surrounding the coil to collapse back upon itself. When this happens, the coil gets voltage through self-induction, but since there is a resistor across the coil terminals, there is a path for any current flow as a result of this voltage. Thus, arcing of the sensitive relay contacts is eliminated.

6-20. For testing purposes, an electrically heated thermal test unit is heated by operation of the test switch. The heating of this unit furnishes a current in excess of the 4 milliamperes required for operation of the sensitive unit to actuate the system and make the warning light come on.

6-21. *Polarity check.* The polarity of the thermocouples should be checked after a power package change or repair, or following the replacement of assemblies containing all or part of a fire detection circuit. A fire detection system tester or the lowest amperage or voltage scale on the standard dc volt-ohm-milliammeter is usually satisfactory for a polarity check. The positive and negative leads of the meter are connected respectively to the positive and negative leads of the fire detection circuit involved. Check the circuit wiring diagram. For the circuits connected to plug terminals A and B, C, D, etc., the first lettered terminal is positive and the second negative in that order for all circuits. Heat the individual thermocouples in the circuit successively by means of a hot soldering copper and check for meter deflection. Be careful not to ground out the thermocouple wiring with the soldering copper. If the polarity is correct, the meter will deflect in a clockwise direction. If meter deflection is counterclockwise, reverse the connections on the thermocouple. The need for a polarity check is very great, since a reversed thermocouple will not only fail to operate the system but it will have a tendency to counteract the output of other correctly connected thermocouples.

6-22. **Photoelectric Circuit.** This type of fire detection system uses the varying resistance of a photoconductive cell in the detector unit to originate a fire signal. The detector cell consists of a glass envelope, inside which a coating of infrared sensitive lead sulphide is deposited. The resistance of the deposit changes rapidly when exposed to the radiation emitted by a flame. The resistance of the cell is in series with resistors of a resistance network in the power unit. The network is capacitance coupled to the grid of an input tube of the amplifier section of the power unit. The power supply of the power unit applies a dc voltage across the series resistances. When a flame causes the cell resistance to fluctuate, a pulsing dc signal is fed to the amplifier. The amplifier is sensitive only to signals of a frequency between 7 and 60 cycles per second. It rejects signals caused by radiation from sunlight and other sources. If the input signal is within the frequency range, the amplifier functions to energize the two warning lights through a transformer. The light burns steadily so that the warning signal can be distinguished from an overheat warning, which is usually a flashing of the lights. If the fire is extinguished, the warning lights go out as soon as the flame disappears.

6-23. Series limiting resistors in the resistor-mixing network of the power unit are arranged so that an input cable from one detector can be short-circuited or opened without interfering with the proper operation of the other detectors, (see fig. 15). False signals resulting from moisture are prevented by the use of special harness for the input cables and by hermetic sealing of the power units. The input cables are also shielded to prevent electrical noise from affecting the system.

6-24. The test system makes a complete functional test of the detection system. The selector switch has positions A through G, corresponding to detectors A through G. A test light is an integral part of each detector; as shown in figure 15, operation of the test switch merely

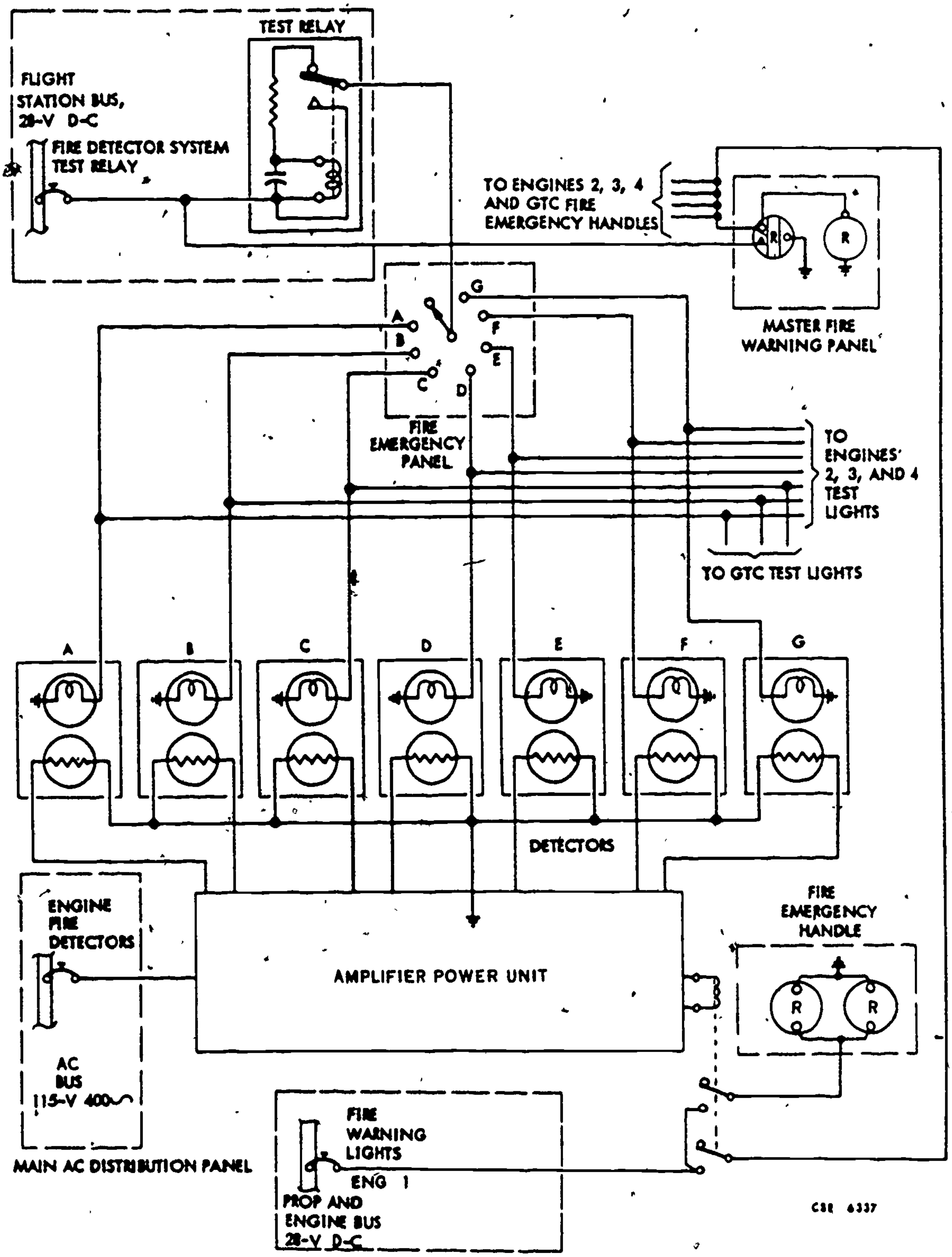


Figure 15. Photoelectric circuit.

closes, dc circuits to energize these lights. The dc supplied to the lights is pulsed at a frequency of 10 cycles per second by an interrupter type test relay. The detector cells are highly sensitive to a 10-cycle frequency; therefore, they originate a signal in the same manner as if exposed to flame radiation. The test light circuit permits individual testing of each detector. If the test switch is positioned at A, for example, each of the lights in the five A detectors starts flashing. One A detector is located in each nacelle, and one is in the gas turbine compressor compartment; therefore, the lights should come on in all five of the fire emergency handles. The lights in the three gas turbine compressor detectors operate when the switch is positioned at A, B, and C. The test checks continuity of circuits, operation of the individual detectors, and operation of the five power units all at one time.

6-25. On some later aircraft a master fire warning panel, located on the pilot's instrument panel, has been added to the fire detection system. This panel was added so that a more noticeable warning signal would be given in case of a fire or overheat condition. The signal from a fire detector is transmitted to a power unit in the same manner as that just discussed. The power unit then energizes a relay which closes a circuit from a FIRE WARNING LIGHTS circuit breaker on the copilot's circuit breaker panel to lights in the fire emergency handle and the master fire warning panel. The master fire warning panel is common to all five fire detection systems and is energized when any detector produces a warning signal or when the fire detector system test switch is operated. A press-to-test feature is incorporated on the master fire warning light. When the master fire warning light comes on, the fire emergency handles must be checked to determine the location of the fire or overheat condition.

6-26. A Fireye tester with an oscilloscope or VTVM may be used to help isolate troubles in defective fire detection system circuits of the photoelectric type. The tester provides easy access to the power unit and detector circuit so that flight line maintenance personnel can check the fire detector circuit for continuity and sensitivity.

6-27. Operational use of this tester is to determine detector system operation capabilities. A detector output signal on the oscilloscope is determined after selecting a detector position with the test switch on the fire emergency control panel and turning the selector switch on the tester to the same detector position. To check the detector circuit for electrical interference, leave the test switch on the fire emergency control panel in the NORMAL position. Select a detector position with the tester selector switch. Check the detector cable for electrical interference by gently flexing the cable at each connector while watching the oscilloscope or VTVM for signs of interference. Check the detector for electrical interference by completely shielding the detector from light and checking the oscilloscope or VTVM for signs of interference. Interference will appear on the oscilloscope as sharp spikes of irregular length and frequency. Noise will appear on the VTVM as rapid movements of the pointer.

6-28. **Continuous Cable Circuit.** The continuous cable circuit fire detector system may consist of two sensing loops in each nacelle: one forward, which is installed on the movable cowl segments; and one aft of the firewall, which is installed in the vicinity of the bleed air ducts and between the tailpipe and the shroud. A separate fire detector control is provided for each sensing element loop. Test relays, flasher units, and control boxes serve to interpret the signals from the nacelle detector system and the gas turbine unit (GTU) fire detector system. The warning signal is then conducted to the indicator lights in the handle of the ENGINE OVERHEAT & FIRE CONTROL switches, and to the master fire warning lights. A flashing signal on these lights indicates an overheat condition, and a steady continuous illumination indicates a fire condition.

6-29. The fire detector sensing loops are made up of segments installed around the cowl and the shroud. These segments consist of a center conductor imbedded in a semiconducting compound and inclosed within a tube. The outer tube is bonded to ground, and the resistance between the center conductor and the grounded tube forms one leg of a balanced bridge circuit in the bridge unit. The semiconducting compound has a negative temperature coefficient; that is, as its temperature rises, its resistance decreases. A fire in the nacelle will cause the resistance of this compound to decrease, and the current will flow from the center conductor to ground in the sensing loop. When a fire occurs, the rise in ambient temperature causes an unbalance in the bridge circuit, as shown in figure 16, and the resulting current flow actuates a relay in the bridge unit, completing the circuit to illuminate the master fire warning light and the warning light in the control switch handle.

6-30. When the test switch, also shown in figure 16, is placed in the test position, it completes the circuit to actuate the fire detector test relay and ground out the detector loop. This creates an unbalance in the bridge circuit, illuminating the fire warning lights.

6-31. Let us discuss the relationship of the continuous cable circuits in a four-engine aircraft. For reasons of simplicity, figure 16 shows only one such circuit. In a four-engine aircraft there

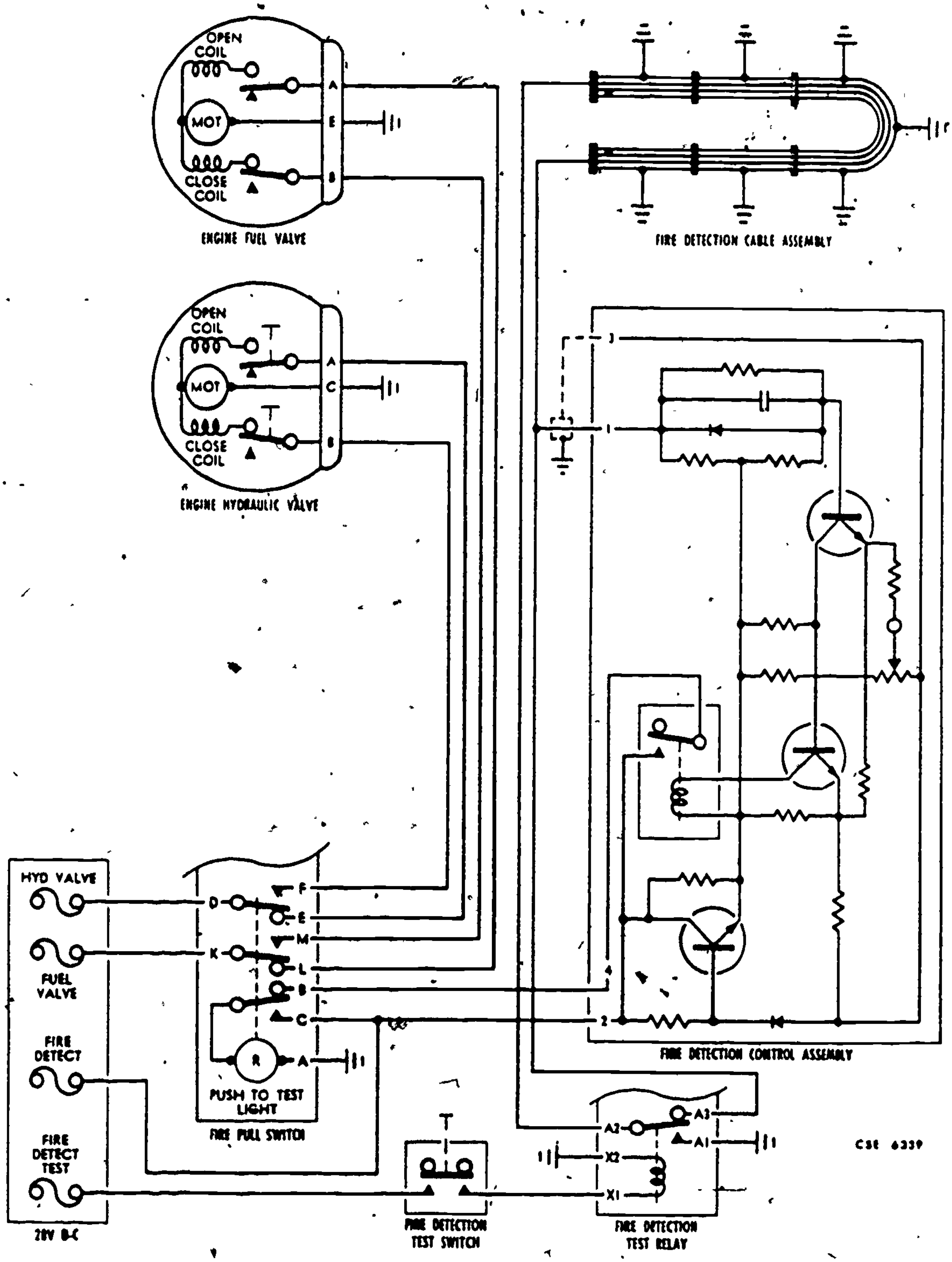


Figure 16. Continuous cable circuit.

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may be four fire detection cable assemblies, one for each engine. Each cable assembly consists of a number of sensing elements connected in series with each other. The cables used in each engine nacelle may contain nine series-connected sensing elements. Each cable assembly is routed through its respective engine nacelle and around the engine, following a path where fire is most likely to occur. Each sensing element consists of two Inconel wires incased in a temperature-sensitive ceramic material. The ceramic material is the dielectric which insulates the wires from each other at normal temperatures. One of the wires is connected to a source of dc power in a control unit assembly, and the other wire is grounded to the connector fittings at each end of the sensing element. The wires and ceramic material are incased in a shield made of Inconel, which is a good heat conductor. When a fire occurs in one of the engine nacelles, the resulting temperature rise causes the electrical resistance of the ceramic material to decrease. The decrease in resistance permits a small current to flow between the two wires and to ground.

6-32. Each of the four fire detection control assemblies contains a single-pole, single-throw relay, and a three-transistor relay control circuit, and is connected to its respective fire detection cable, fire pull switch, and a source of 28-volt dc power. When a fire occurs in one of the engine nacelles, the current flow to ground causes a switching action in the three-transistor relay control circuit and closes the relay. When the relay inside the control assembly closes, a circuit is completed between the 28-volt dc power distribution panel and the warning lamp in the handle of the fire pull switch, causing the lamp to light. Activating the fire pull switch, also shown in figure 16, closes the fuel and hydraulic valves and stops the flow of combustible liquids to the engine.

6-33. The fire detection test switch is a push-button type switch. When this switch is pressed, a circuit is completed between the 28-volt dc power distribution panel and the actuating coil of the fire detection test relay. The fire detection test relay is a four-pole, double-throw relay. Each set of relay contacts is connected to its respective fire detection cable assembly and fire detection control assembly. When the relay is energized, the cable assembly in each engine nacelle is grounded to simulate an excessive heat condition to its respective control unit assembly. The warning lamp in each of the four fire pull switches will come on to indicate satisfactory control unit operation and continuity through each cable assembly (see fig. 16).

6-34. Operational checkout of the continuous cable detection system is conducted in two parts: (1) the system checkout, and (2) the cable assembly checkout. The system checkout is conducted each time a component of the system is replaced. The cable assembly checkout is conducted when a cable assembly is suspected of having had its resistance value changed. The checkout is conducted with the aid of a megger. Figure 17 shows the insulation resistance values of each sensing element in each nacelle of a typical four-engine aircraft. Notice the different values of insulation resistance in the various stations of each engine nacelle. For example, station 125, engine nacelle Nr. 1, has a sensing element, 703084, that has an insulation resistance of 0.167 megohm.

6-35. Disconnect the electrical harness from sensing elements 703084 and 706060 At either sensing element, connect one megger lead to the center conductor and the other megger lead to the sheath of the cable assembly with the megger set to the 500-volt output scale; the megger should indicate an insulation resistance value greater than 0.124 megohm for engines Nrs. 1, 2, and 3. For engine Nr. 4, the resistance value should be greater than 0.247 megohm.

6-36. The resistance of the sensing element loop is determined with a VTVM. By connecting one vacuum tube voltmeter lead to the center conductor of sensing element 703084 and connecting the other voltmeter lead to the center conductor of sensing element 706060 with the voltmeter set to indicate resistance, the VTVM should indicate a resistance value of approximately 62 ohms for engines Nrs. 1, 2, and 3 and approximately 48 ohms for engine Nr. 4.

6-37. This concludes the discussion of the various types of fire and overheat warning systems you will encounter on most aircraft. As far as the overheat systems are concerned, most of the aircraft use thermoswitches with the lower temperature settings in the overheat detector circuit. On certain aircraft there is a separate warning for an overheat condition, while on other aircraft it is combined with the fire warning light. In these installations a flashing light indicates an overheat condition, whereas a steady illumination of the fire warning light signifies a fire condition. Next, let's take up a typical master warning and caution system. A typical master warning system provides visual indication of malfunctions in such systems as takeoff warning, door warning, smoke detection, and emergency alarm systems.

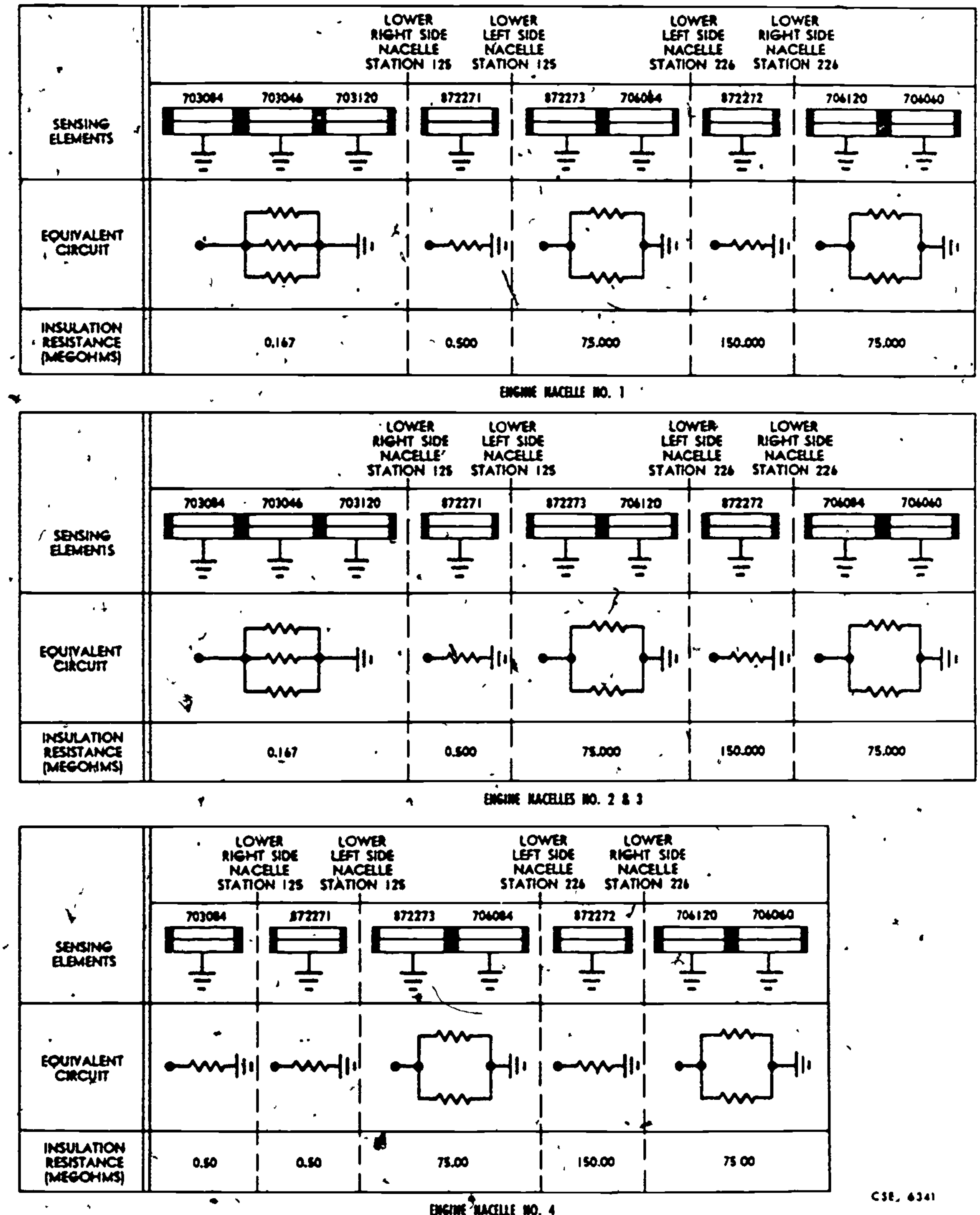

Figure 17. Continuous cable resistance values.

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7. Master Warning and Caution System.

7-1. The master warning and caution system provides the aircrew with a visual indication of a malfunctioning airplane system. Two kinds of malfunction signals are furnished: the master warning lamp assembly and its individual warning lamp assemblies provide red warning signals, and the master caution lamp assembly and its individual caution lamp assemblies provide yellow caution signals. The master warning and caution system is equipped with a ground protection feature that automatically prevents unnecessary ground operation of the lamp assemblies by opening the lamp ground circuits when external power is applied to the airplane. An override switch is provided to override the ground protection circuit when it is necessary to have the master warning and caution system in operation. Let us discuss the components found in this type of system.

7-2. **Components.** Both the master warning lamp assembly and the master caution lamp assembly contain three lamps connected in parallel. The two lamp assemblies are connected directly to a source of 28-vdc power. The 28-vdc circuit to ground is completed through the switching action of two point-contact transistors, which are an integral part of each master lamp assembly, as shown in figure 18. The two lamp assemblies are identical except for the different colored filters and the addition of a time-delay circuit within the master caution lamp assembly. The time-delay circuit causes the master caution lamp assembly to light approximately 1 second after the individual caution lamp assembly has been lighted.

7-3. Each individual warning lamp assembly and each individual caution lamp assembly contain two lamps connected in parallel. Each assembly is connected to a source of 28-vdc power through its own normally open fault switch. The individual fault switch may be a pressure-operated switch, a thermal switch, a make-break contact switch, or a relay. The internal circuits of the warning and caution assemblies are identical.

7-4. *Light test relay.* The light test relay, as shown in figure 18, is actuated by pressing the MALF & IND LIGHTS TEST switch. When the relay is actuated, a circuit is completed between the 28-volt power distribution panel and each of the individual lamp assemblies. When this circuit is completed, both master lamp assemblies and each individual lamp assembly are lighted. The master warning and caution system ground protection override switch must be in WARNING & CAUTION IND GROUND CHECK position before lamps will light.

7-5. Dimming relay A is actuated by momentarily placing the MALF & IND LIGHTS switch in DIM position. If the panel variacs (autoreset switches) are both rotated 25° clockwise from the OFF position, the relay will hold in the actuated position after the dimming switch has returned to neutral position. When the relay is actuated, the ground is removed from each of the lamp assemblies. The lamps within each lamp assembly must then find ground through individual resistors connected in series with each lamp and ground. The lamps dim as a result of the voltage drops across each of the resistors.

7-6. Dimming relay B is actuated by momentarily placing the MALF & IND LIGHTS switch in DIM position. If the panel variacs are both rotated 25° clockwise from OFF position, the relay will hold in the actuated position after the dimming switch has returned to neutral position. When the relay is actuated, two circuits are completed. A circuit is completed from the 28-volt power distribution panel through terminals A2 and A1 of dimming relay B and through terminals X1 and X2 of dimming relay A. This is the holding circuit for dimming relay A, and the relay remains actuated after the dimming switch returns to neutral position (see fig. 18).

7-7. Likewise, a circuit is completed from the 28-volt power distribution panel through terminals A2 and A1 of dimming relay B, through the closed contacts of the switches in the right and left panel variacs, and through terminals X1 and X2 of dimming relay B. This is the holding circuit for dimming relay B, and the relay remains actuated after the dimming switch has returned to neutral position.

7-8. There are two single-pole, single-throw autoreset switches shown in figure 18. The switch contacts close when the variacs are rotated approximately 25° clockwise from the OFF position. The two switches are connected in series with each other. When both switches are closed, the holding circuit for dimming relay B is completed.

7-9. The MALF & IND LIGHTS dimming switch is a single-pole, double-throw, spring-loaded switch. The switch is held in a neutral position by the spring-loading feature. When the switch is momentarily placed in the DIM position, dimming relay B is momentarily actuated. If the two autoreset switches are closed, the relay remains actuated after the dimming switch returns to neutral position. When the dimming switch is momentarily placed in BRIGHT position, a ground is established which causes the actuating current to bypass the dimming relays and both relays are deactuated.

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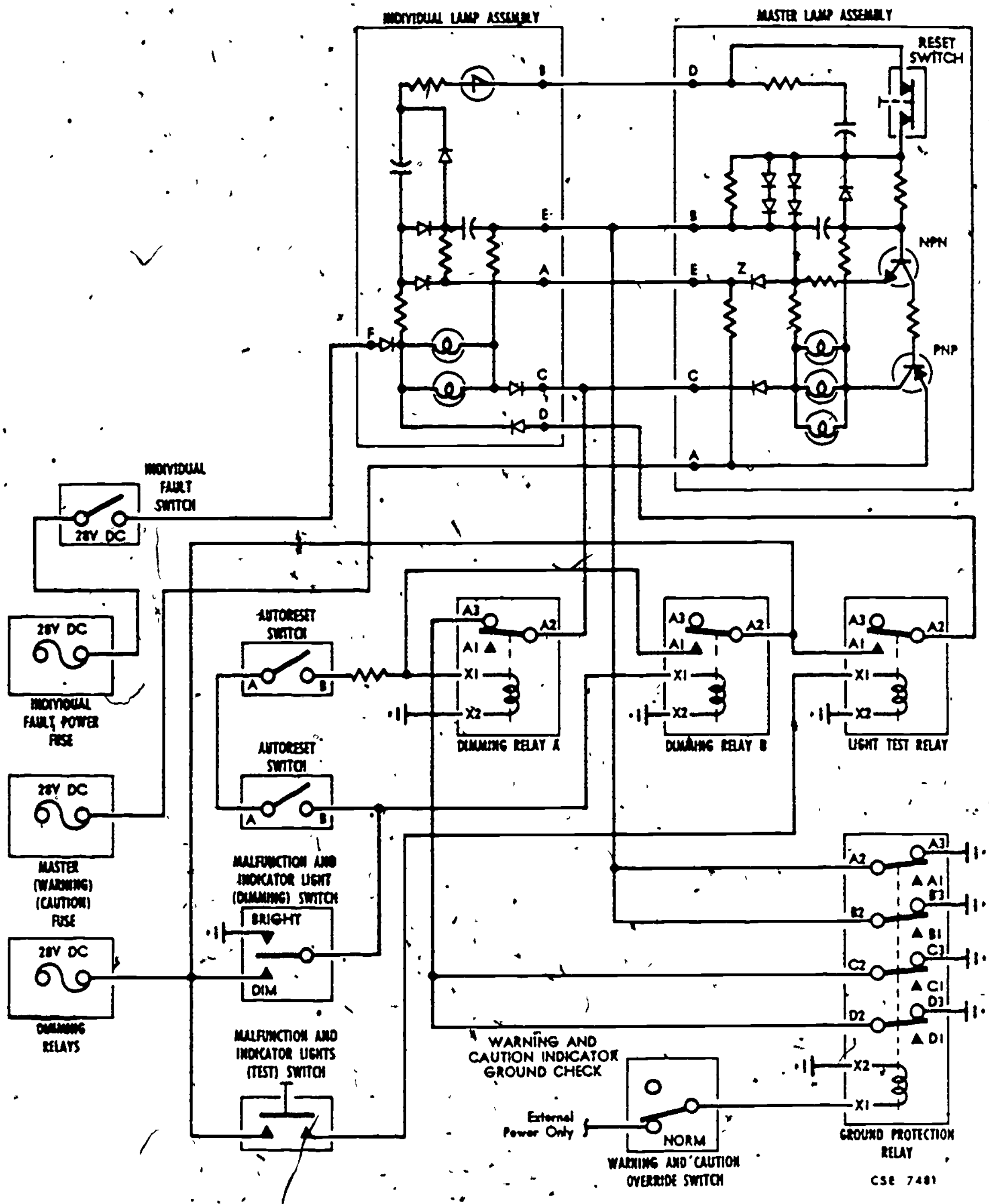

Figure 18. Master warning and caution system.

7-10. The MALF & IND LIGHTS TEST switch is a push-to-make switch. When the switch is pressed, a circuit is completed between the 28-volt power panel and the actuating coil of the light test relay. When this circuit is completed, the light test relay is actuated (see fig. 18).

7-11. *Fault switches.* Fault switches are assorted types of switches or circuit-closing devices in the master warning and caution system. They are used to indicate malfunctions in various locations in the aircraft, such as in the anti-ice, fuel pumps, oil low, ac generator, hydraulic pumps, or canopy unlock components.

7-12. *Master warning lamp assembly.* The master warning lamp assembly, also shown in figure 18, consists of an airtight container with a red filter faceplate, three parallel-connected light bulbs, and required circuits to connect the light

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bulbs to a source of 28-vdc power. The master warning lamp assembly is lighted when any one of the individual warning lamps signals is illuminated to indicate that trouble has developed within its system. When the master warning lamp assembly is lighted, the words "MASTER WARNING PUSH TO RESET" appear in red letters on the face of the filter. When the master warning lamp assembly is pushed, the lamp goes out and remains out until a different individual warning lamp signals of trouble within its system.

7-13. Each individual warning lamp assembly consists of an airtight container with a red filter faceplate, two parallel-connected light bulbs, and required circuits to connect the light bulbs to a source of 28-vdc power. When an individual warning lamp assembly is lighted, the callout of the system in which trouble has developed appears in red letters on the face of the filter. The lamp remains lighted until the trouble within its system has been corrected.

7-14. *Master caution lamp assembly.* The master lamp assembly consists of an airtight container with a yellow filter faceplate, three parallel-connected light bulbs, and required circuits to connect the light bulbs to a source of 28-vdc power. The master caution lamp assembly is lighted approximately 1 second after any one of the individual caution lamp assemblies signals that trouble has developed within its system. The time-delay feature and the yellow filter are the only differences between the master caution lamp assembly and the master warning lamp assembly. When the master caution lamp assembly is lighted, the words "MASTER CAUTION PUSH TO RESET" appear in yellow letters on the face of the assembly. When the master caution lamp assembly is pushed, the lamp goes out and remains out until a different individual caution lamp signals trouble within its system.

7-15. The individual caution lamp assemblies are identical with the individual warning lamp assemblies, except for the color of the filter. When an individual caution lamp assembly is lighted, the callout of the system in which trouble has developed appears in yellow letters on the face of the assembly.

7-16. *Master warning and caution system ground protection override switch.* The master warning and caution system ground protection override switch, shown in figure 18, is a two-position (WARNING & CAUTION IND GROUND CHECK and NORM) switch located in the ground protection circuit between the external power source and the closing coil of the ground protection relay. When the override switch is in the NORM position, the closing coil circuit is completed and the lamp ground circuits are open. When the override switch is in the WARNING & CAUTION IND GROUND CHECK position, the closing coil circuit is open and the lamp ground circuits are completed.

7-17. The ground protection relay (fig. 18) is used to open the ground circuits for the master warning and caution system lamps when external power is applied to the airplane. The power for the closing coil of the relay, supplied by the external power unit, is routed through the ground protection override switch. The ground protection relay is deenergized to complete the ground circuits for the lamps when the aircraft is furnishing its own electrical power or when external power is being furnished to the aircraft and the ground protection override switch is placed in the WARNING & CAUTION IND GROUND CHECK position.

7-18. **Operation.** When trouble develops within an aircraft system, the fault switch closes. A circuit is completed from the 28-volt power distribution panel through the fault switch, through terminals F and C of the individual lamp assembly, and through the normally closed contacts of the dimming relays to ground (see fig. 18). When this circuit is complete, the individual lamp assembly is lighted.

7-19. Each individual lamp assembly includes a tripping circuit that controls the voltage to the associated master lamp. The tripping circuit allows voltage to be applied to the master lamp when a fault occurs in the airplane system being monitored by the light. The tripping circuit maintains the application of voltage to the master light until the fault is cleared or the master light is pushed to the RESET position.

7-20. When fault voltage is applied through the individual lamp to the master lamp, the transistor switching circuit in the master lamp allows voltage from the applicable MASTER fuse in the 28-volt power distribution panel to light the master lamp (see fig. 18).

7-21. When the master lamp assembly is pushed to the RESET position, a momentary type switch in the master lamp opens the circuit from the individual lamp, and the tripping circuit in the individual lamp prevents reapplication of voltage to the master lamp until a fault develops within another system. When another fault occurs, the cycle is repeated.

7-22. When the MALF & IND LIGHTS TEST switch is pressed, the light test relay is actuated. A circuit is completed from the 28-volt power distribution panel through the light test relay contacts to terminal D of each individual lamp assembly. From terminal D to ground the circuit is the same as the circuit to which power is furnished through the fault switch. The master warning lamp assembly, the master caution lamp assembly, and each of the individual lamp assemblies are lighted when this circuit is completed

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(see fig. 18). Next, we turn to the operation of the various circuits that cause the master warning and caution system to operate.

7-23. *Takeoff warning circuit.* In the following discussion refer to figure 19. The takeoff warning circuit monitors various systems in the aircraft through a set of relays. When the aircraft is ready for flight, a green light will illuminate on the main instrument panel, indicating that the various circuits monitored by the takeoff warning system are ready for flight. The relays monitored by a typical takeoff warning system are: the door open relay, the spoilers closed relay, the thrust-reversers extended relay, the thrust-reversers unlocked relay, the flap position takeoff relay, the horizontal stabilizer trim relay, the essential navigator's bus relay, the isolated ac bus off relay, and the isolated ac bus off indicator relay. The flap takeoff position relay is wired to a flap position limit switch, which closes only when the flaps are in the takeoff position. The circuit connecting the relays with the takeoff warning indicator circuit breaker passes through the nose landing gear position switch. The circuit is broken when the nose landing gear is retracted. The automatic flight control system is connected into the system through the spoilers closed relay and the essential navigator's bus relay. The autopilot must not be engaged before the TAKEOFF light comes on. The stabilizer relay must be closed by operating either the pilot's or copilot's hydraulic pitch trim control handle switch. The door open relay is monitored by the takeoff warning circuit, so that if any of the doors are open, the green TAKEOFF light will not come on. The TAKEOFF light will not operate if the wing spoilers are deployed. The wing spoiler system is connected to the takeoff warning system through the spoilers closed relay. The thrust reverser system is connected to the takeoff warning system through the thrust reverser's unlocked relay and the thrust reverser's extended relay. The TAKEOFF light will not come on if the thrust reversers are unlocked or extended. The takeoff warning system monitors the isolated ac bus and the navigator's essential bus to insure that instrument power is available.

7-24. *Smoke detector warning circuit.* The smoke detector warning circuit is composed of a number of detector devices, an amplifier, test selector switch, and warning lights. The detectors are mounted in varying parts of the cargo compartment and under the flight deck. Essentially, the detectors are composed of a light and a photocell. The light is shuttered so that the beam is parallel with the face of the photocell. As long as

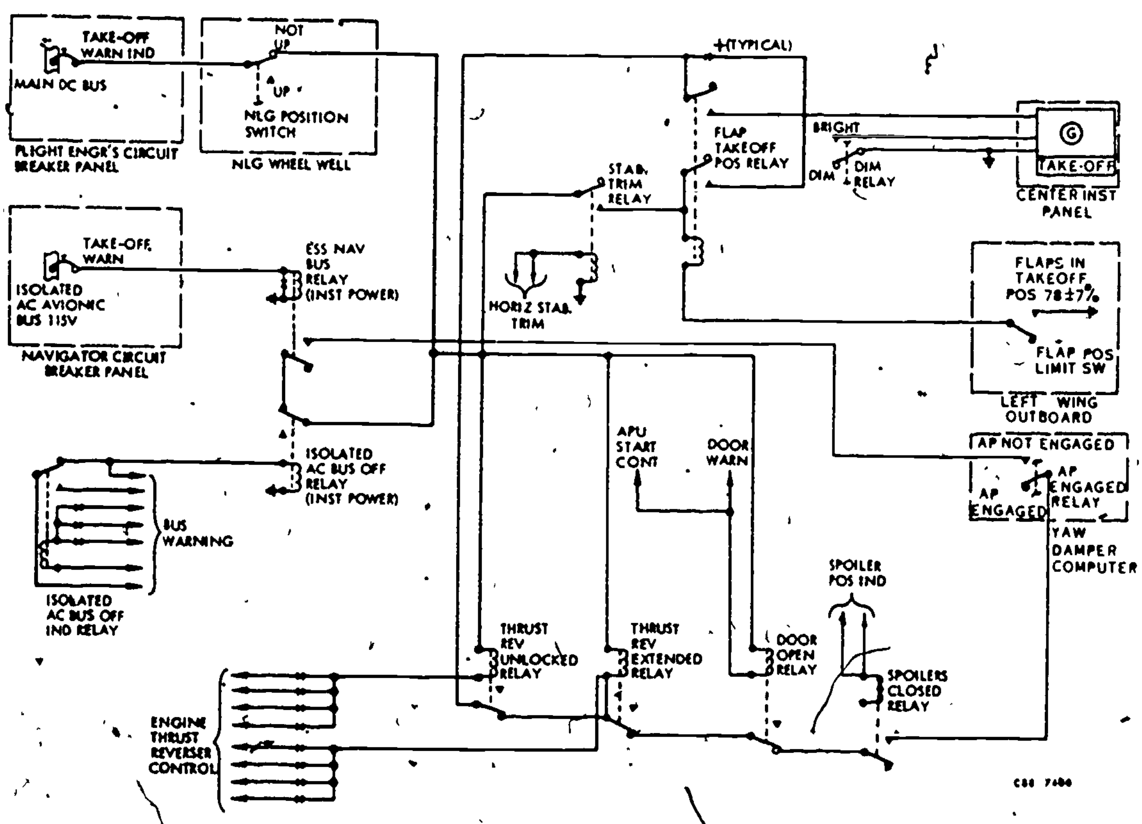

Figure 19. Takeoff warning circuit.

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the air is clear, the light beam cannot reach the photocell. The amplifier sends a signal to the CARGO SMOKE lights on the flight engineer's panel, and the annunciator panel that identifies an individual warning circuit. The signal travels from the annunciator panel to the CAUTION lights on the main instrument panel. If the ability of the air in the detector to transmit light is reduced by 30 percent, as in a fire, light will be reflected to the photocell to send a signal to the amplifier. The amplifier sends a signal to the CARGO SMOKE lights on the flight engineer's panel and the annunciator panel. The test switch in the circuit shines a light directly into the photocell in the detector, thereby testing the detector, the amplifier, and the CARGO SMOKE and CAUTION lights.

7-25. *Emergency alarm bell and warning horn circuit.* An emergency alarm bell and warning horn system is provided to alert all personnel on the aircraft if an emergency arises. The alarm bell and warning horn circuit consists of master alarm bells, slave bells, an alarm bell switch and a warning horn. A master alarm bell is located in the control cabin and controls the slave bells. The slave bells are located in various parts of the aircraft.

7-26. The master alarm bells must operate to provide a cyclic ground for the slave bells. The warning horn is energized when the alarm bells are turned on. When the alarm bell switch is operated, 28 volts dc is supplied to the alarm bells and warning horn from the battery relay and circuit breaker panel. A capacitor is shunted across the terminals of each master alarm bell to prevent arcing at the bell contacts.

7-27. *Door warning circuit.* The door warning circuit is provided to warn the pilot if the crew entry door or cargo door is not properly secured. The circuit consists of warning switches actuated by the doors, warning lights, and a circuit breaker on the main circuit breaker panel. When all the doors are closed and latched, the warning switches are all open and there is no ground for the warning light circuit. With power on the airplane buses, the door warning light will come on if any of the doors are not closed and latched.

7-28. The door warning circuit has a door locked limit switch that indicates the closed condition of the entry door. With the door open, the switch contacts are closed, supplying a ground to the DOOR NOT LOCKED indicator, causing the light to illuminate. In some cases when the door is closed, it must be latched to give a door locked indication. Another switch in parallel with the door locked limit switch is required to be actuated by the latch mechanism in order to turn off the warning light. For example, if a crew door is in the closed but not latched position, the warning light will remain on until the latch switch is actuated. On some aircraft this is accomplished by pushing in the crew door and placing the lower handle in the UP position. With the handle in the UP position, the door is latched and the latch switch plunger is depressed by the actuator arm attached to the torque bar. This opens the ground circuit provided by the switch and turns off the warning light. Foldout 5 shows the door warning circuits of a typical cargo type aircraft. These door warning circuits are equipped with door not locked indicators that may be located in the flight station as well as in the cargo compartment. They are as follows:

- CREW DOOR NOT LOCKED light
- RAMP NOT LOCKED light
- CARGO DOOR SYSTEM ARMED light
- PRESSURE DOOR NOT LOCKED light
- PETAL DOORS NOT LOCKED light
- LH TROOP DOOR NOT LOCKED light
- RH TROOP DOOR NOT LOCKED light
- STABILIZER ACCESS DOOR NOT LOCKED light

7-29. As shown in foldout 5 the indicators will illuminate when their respective limit switches complete a circuit to ground. Troubleshooting these circuits will be discussed later in this chapter.

7-30. Some aircraft may have a pilot's and copilot's paradrop and ADS (air drop system) indicator panels. These indicators are listed below:

- EXTERNAL CL light
- INTRANSIT light
- PRESS OPEN light
- PARA OPEN light
- PETAL OPEN light

7-31. The EXTERNAL CL light is illuminated when the petal doors or auxiliary petal doors and ramp are closed and locked. This light remains illuminated until the pressure door is closed and locked. The INTRANSIT light is illuminated when the pressure door locked limit switch is actuated by unlocking the pressure door. This light stays illuminated until the ramp and petal doors are completely open and the all-open relay is energized. When this relay energizes, the ground side of the circuit is broken and the light is extinguished. The AUX OPEN light is illuminated when the auxiliary petal doors and the ramp have reached the end of travel and the all-open relay is energized. The circuit is grounded through the all-open relay and the light is illuminated. The PETAL OPEN light is illuminated when the petal doors and ramp have reached the end of their travel and the all-open relay is energized. The circuit is grounded through the all-open relay, and the light is illuminated. The position of the DOOR SELECT SWITCH on the pilot's paradrop

and ADS panel determines whether the AUX OPEN light or the PETAL OPEN light is illuminated.

7-32. The crew door interphone panel includes an ARMED light, an INTRANSIT light, and an ALL OPEN light. The ARMED light is illuminated when the DOOR ARMING switch on the pilot's paradrop and ADS panel is positioned to ARM. The INTRANSIT light is illuminated when the pressure door locks are actuated to the unlock position, and it remains illuminated until the all-open relay is energized to break the circuit. The ALL OPEN light is illuminated when the all-open relay is energized. The all-open relay is energized when the pressure door, ramp, and petal doors or auxiliary petal doors are open to the desired positions. While we are in this area, let's discuss a typical bailout warning system.

8. Bailout Warning System

8-1. The bailout warning system provides the pilot with a means of communicating with each crewmember. Each crewmember has an amber alert signal light, controlled by the pilot, which provides a flashing alert signal indicating that bailout may become necessary. Also, there is a red warning signal light that illuminates when bailout is ordered. When the CREW HAS EJECTED signal light comes on, it tells the pilot that all the crewmembers have ejected. The electrical circuits that are associated with these lights are called the bailout alert, bailout warning, ejection indication, and mayday capability control. In the following discussion, refer to figure 20 for the bailout warning circuits.

8-2. **Alert Circuit.** The bailout alert circuit contains a switch, amber signal lights, and a flasher unit. When the bailout switch, located in the pilot's station, is placed in ALERT position, a circuit is completed from a 28-vdc power distribution panel, through the switch, and through the flasher unit to each of the parallel-connected alert signal lights. The lights flash on and off as long as the bailout switch remains in ALERT position. The flasher unit causes the bailout alert lights to flash on and off at the rate of approximately 40 cycles per minute.

8-3. **Warning Circuit.** The bailout warning circuit contains a switch and red signal lights. When the bailout switch located in the pilot's station is placed in the BAILOUT position, a circuit is completed from the 28-volt power distribution panel through the switch to each of the warning lights. The lights come on and remain on as long as the bailout switch is in BAILOUT position.

8-4. **Indication Circuit.** The ejection indication circuit contains switches and an indication lamp assembly. When the crewmembers eject, the switches are closed, establishing a circuit between the 28-volt power distribution panel and the indication lamp assembly. These are plunger-operated, double-pole, double-throw switches.

8-5. **Mayday Capability Control.** When the bailout switch or the alert switch is positioned to the BAILOUT or ALERT position, the aircraft mayday relays are actuated. On aircraft with escape capsules installed, the mayday relays are also actuated when any one of the capsule doors is closed. Actuation of the mayday relay will turn on the emergency communication equipment in the aircraft.

8-6. When the bailout and alert switches are positioned to OFF, the mayday relays are deactuated and operation of all systems is returned to the original configuration.

8-7. If it should be necessary to eject from the aircraft, the pilot's ejection indication switch will be deactuated when the pilot ejects. When the ejection indication switch is deactuated, circuits are completed to provide mayday functions plus continuous radio carrier transmission to allow additional time for ground stations to establish a "fix" on the pilotless aircraft.

8-8. This concludes the discussion on warning circuits. We have mentioned, in general, several types of warning systems. Refer to the applicable TO for operational and troubleshooting checks on a particular warning circuit.

9. Troubleshooting the Warning Circuits

9-1. Normally all aircraft have some type of warning system. The more modern aircraft have what is known as a master warning and caution system, and some of the multi crew aircraft will also have a bailout warning system. These are the two systems that will be discussed in this section.

9-2. **Master Warning and Caution System.** The troubleshooting procedure for the master warning and caution system is based on the results of an operational checkout. Suppose, for example, that one or more individual lamp assemblies do not light when the MALF AND IND LIGHTS test switch is pressed (closed). Refer again to figure 18 for circuits on the master warning and caution system. Looking at figure 18, you can see that a probable cause could be that the bulbs were burned out. If the bulbs are bad, replace them. Another possible cause may be a defective lamp assembly. With the bulbs removed from the lamp assembly and the test switch depressed, there should be 28 volts dc at each bulb socket. If 28 volts dc is present at pin D and zero volts present at each socket (see fig. 18), then the lamp assembly is defective and should be replaced or repaired. Another malfunction might be as follows: during an operational check

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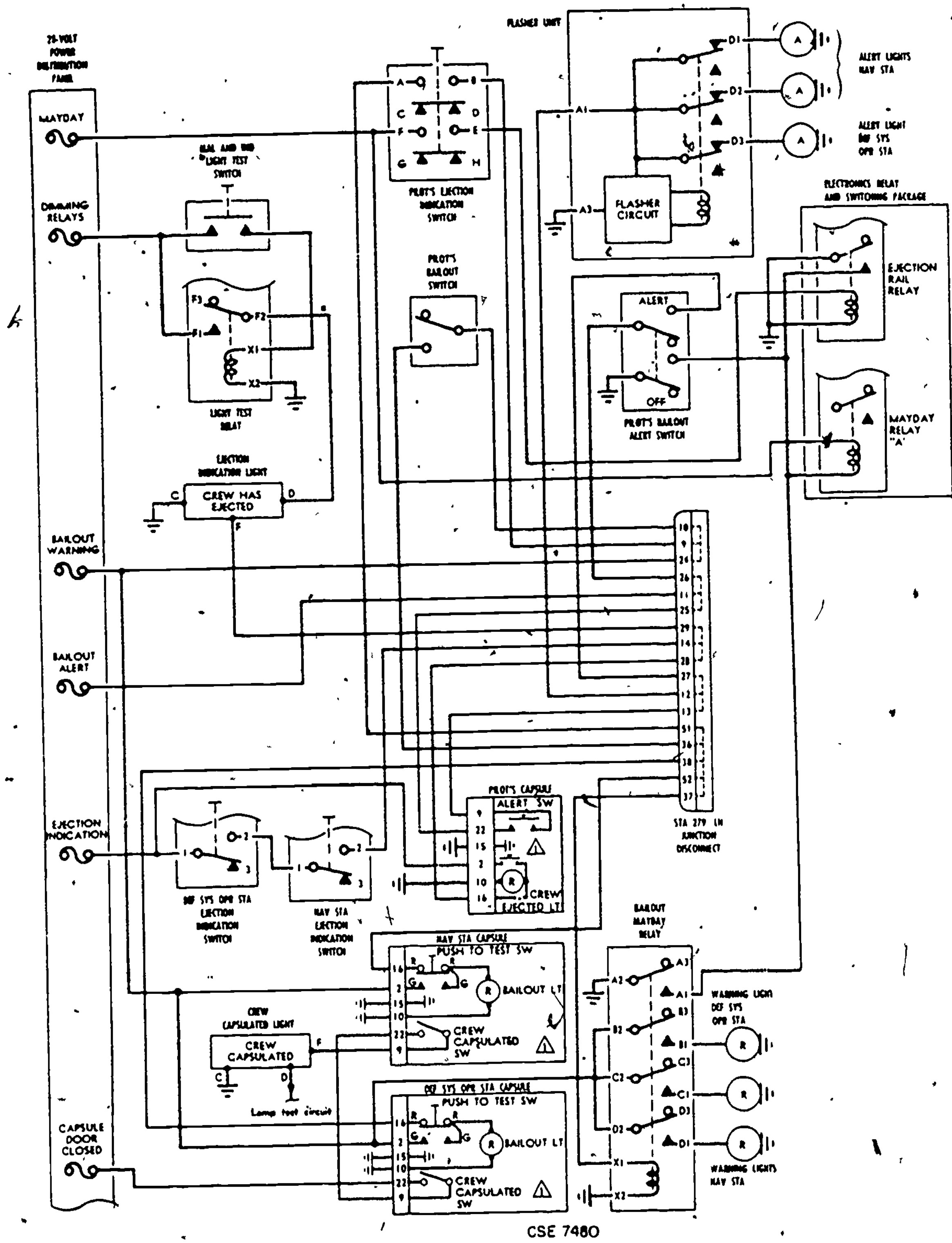

Figure 20. Bailout warning circuit.

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you discover that the master caution lamp assembly does not light when the MALF AND IND LIGHTS test switch is pressed. As shown in figure 18, there are many probable causes. A fuse may be blown because of a short circuit or a hot wire grounded. The light bulbs may be burned out, or there may be an open circuit between components. Now refer again to foldout 5 "Door Warning Circuit." Looking at this diagram, you will notice that limit switches open or close a circuit to ground. Let us consider another symptom and the probable causes. Suppose the CREW DOOR NOT LOCKED warning light will not go on. A faulty resistor in the center fuselage J box may be the cause. If placing the light control on BRIGHT makes the light come on, then the resistor is faulty and should be replaced. Another cause could be a faulty door warning lights relay. If the lights do not come on or are dim when the control is placed to BRIGHT, the relay is faulty and should be replaced.

9-3. **Bailout Warning System.** Troubleshooting the bailout warning system may be accomplished by the use of a PSM–6 multimeter or an equivalent piece of test equipment that indicates voltage and continuity. Figure 20 illustrates a typical bailout warning system. Suppose that none of the amber bailout alert lights operate when the bailout alert switch is placed in the alert position (bulb check good). By referring to figure 20, let us begin by checking the fuse. If the fuse is blown, it is very possible that there is a short circuit or ground in the wiring between the *bailout alert* fuse and the lights. Another cause may be an open circuit in the wiring. Continuity should exist, and there should be no shorts or grounds. If no continuity exists, then check the bailout alert switch, fuse, flasher, and wiring.

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Fuel Systems

THE FUEL SYSTEM is one of the major aircraft systems. The operation of the aircraft depends largely upon an uninterrupted fuel supply. The number of electrical components used in a fuel system necessitates a very thorough understanding of system operation as well as component function by electrical maintenance personnel.

10. Main Fuel Systems

10-1. The information presented in this section provides you with the knowledge required for you to maintain, troubleshoot, and repair the fuel system control circuits and the control system components. A multiengine fuel system has been selected for this discussion because this system contains many components that will be found in other types of Air Force aircraft.

10-2. **System Components.** Control of the fuel system is accomplished through the use of various switches and indicators located on the fuel management panel and the auxiliary panel, shown in figure 21. In the discussion to follow, all reference to component operation will be to numbered switches on these two panels.

10-3. *Boost pumps.* In all there are 32 boost pumps used in this fuel system. There are 4 pumps in each main tank for a total of 16, and 16 more pumps are located in the various auxiliary tanks. Both main tank boost pumps and auxiliary tank pumps are controlled by switches located on the fuel management panel (fig. 21). Four guarded toggle switches, marked MAINS 1, 2, 3 and 4, control main tank boost pumps. By placing a main tank boost pump switch in the ON position, all four pumps in that tank will start simultaneously and supply fuel to an engine.

10-4. The auxiliary fuel pumps are controlled by flow control switches on the fuel management panel. The fuel flow control switches are of the rotary type and control both the feed valves and the auxiliary pumps associated with the selected tank

10-5. All boost pumps are driven by 115/200-volt, 400-cycle, three-phase ac induction motors. The boost pumps are not repaired at the local level. They must be returned to the depot for overhaul where the proper test equipment is available.

10-6. *Fuel valves.* There are several types of valves used in a fuel system. Basically there are three types of fuel valves used in the system under discussion: motor-driven sliding gate, motor-driven plug, and float type control valves.

10-7. The fire shutoff valves are motor-driven sliding-gate-type valves. Each valve is provided with an indicator, located on the valve, to provide a visual means of checking the valve position during operational checks or when performing system maintenance. The valves are individually controlled by a microswitch actuated by throttle linkage and by the fire shutoff switch.

10-8. The cross feed valves are motor-driven rotary-plug-type shutoff valves. These valves are powered by dc from the aircraft bus through the flow control switches. The flow control switches are located on the fuel management panel. A crossfeed valve is also provided with an indicator located on the actuator. The switches for the crossfeed valves are numbered 9, 10, 11 and 12 on the fuel management panel.

10-9. The auxiliary tank engine feed control valves are rotary plug type valves and are numbered 13, 14, 15 and 16 on the fuel management panel. The valves are powered by dc motors. When these valves are operated, two main boost pumps in the main tanks will be deenergized to reduce main tank output, thus insuring auxiliary fuel flow to an engine.

10-10. The system is also provided with two motor-driven sliding-gate-type valves called *interconnect valves.* These valves allow the left wing and aft body tanks to be connected to the right wing, mid body and the forward body tanks. The interconnect valves are controlled by switch number 29 on the fuel management panel. These valves are open during refueling, defueling, and fuel transfer operations.

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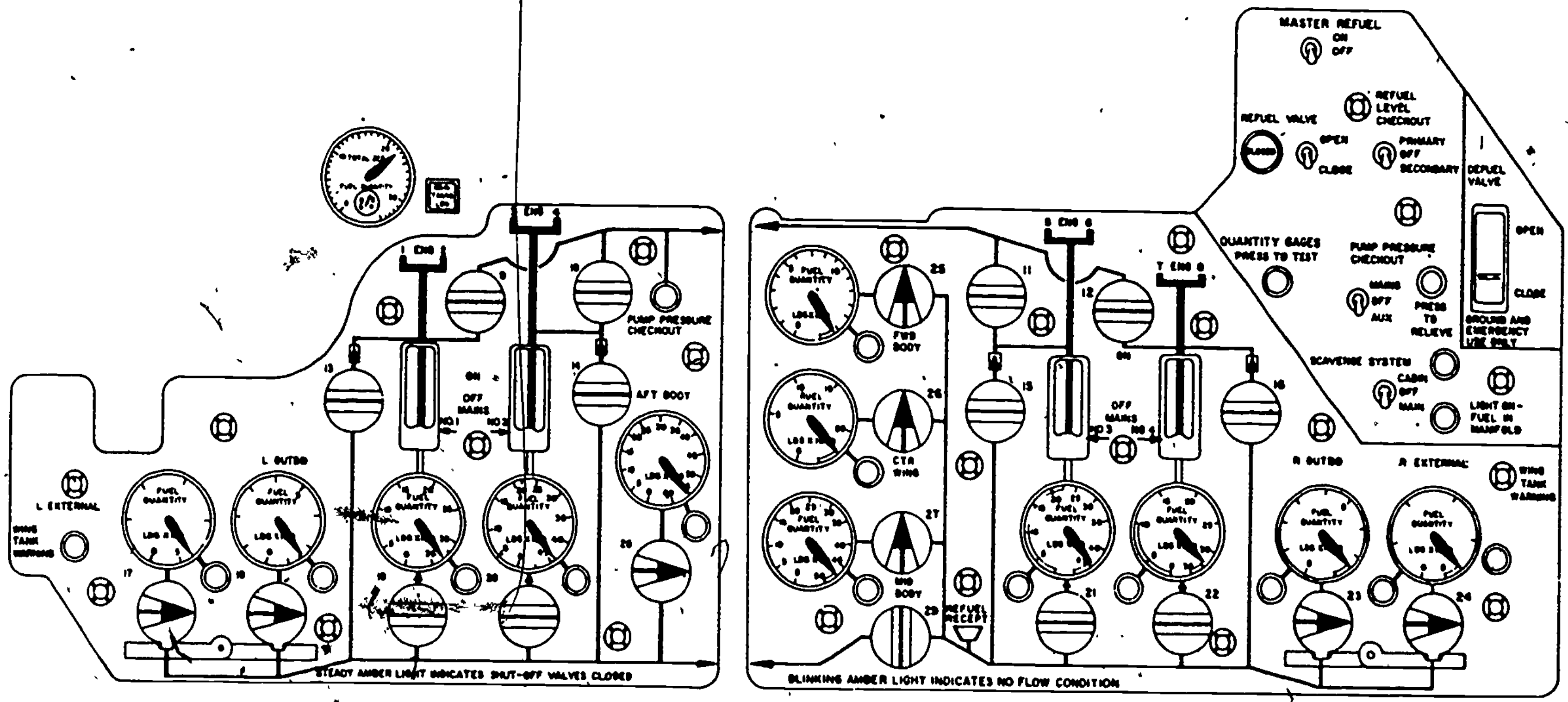

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Figure 21. Fuel management panel.

10-11. A main refuel valve, located in the refuel manifold downstream from the air refueling and single-point refueling receptacles, isolates the refuel manifold from the main fuel manifold. The refuel valve is a sliding gate type valve normally operated electrically, and is controlled by the refuel valve switch on the auxiliary refuel system panel. For emergency operation, the valve may be controlled through a cable system by a refuel valve emergency control lever. The valve incorporates both open and close limit switches to control valve movement and operates a C1 type indicator located on the refuel system panel.

10-12. The defuel valve is a motor-driven gate type valve controlled by the defuel switch on the auxiliary refuel system panel. The defuel valve switch is guarded to the CLOSED position and is also marked GROUND AND EMERGENCY USE ONLY. The defuel valve is used to defuel the fuel tanks through the single point refueling receptacle.

10-13. *Fuel level control valve.* Each fuel tank is provided with one dual fuel level control valve, excepting the Nrs. 1 and 4 tanks, the outboard wing tanks, and the aft body tank, which are provided with two. The purpose of each valve is to admit fuel into each tank during fuel servicing and to shut off fuel flow automatically when the tank is full, either by weight or volume. Fuel can also be shut off at any level less than full when the fuel flow control switches are moved to a CLOSED position or the master refuel switch to OFF position. The valves are normally held closed by spring action against the primary diaphragm (fig. 22). To open the valve with fuel pressure in the main manifold and the valve in the CLOSED position, all three solenoids must be energized and all three pilot valves must be opened. Failure of either poppet valve or any one pilot valve to open should prevent the valve from opening. Moving the fuel flow control switch for the affected valve to REFUEL position should cause the primary and secondary poppet valves and the lockout pilot valve to open. When fuel trapped in both float chambers is drained, gravity acting on each float should cause the primary and secondary pilot valves to open. Finally, when the three pilot valves and two poppet valves are all open, the incoming fuel pressure lifts the primary diaphragm and holds the valve open. The valve may then remain open until both floats are actuated by the rising level of fuel in the tank. Both floats should act to close their respective pilot valves whenever the tank fuel level rises to within 2.10 (± 0.25) inches of the fuel level control valve mounting pad. Both floats

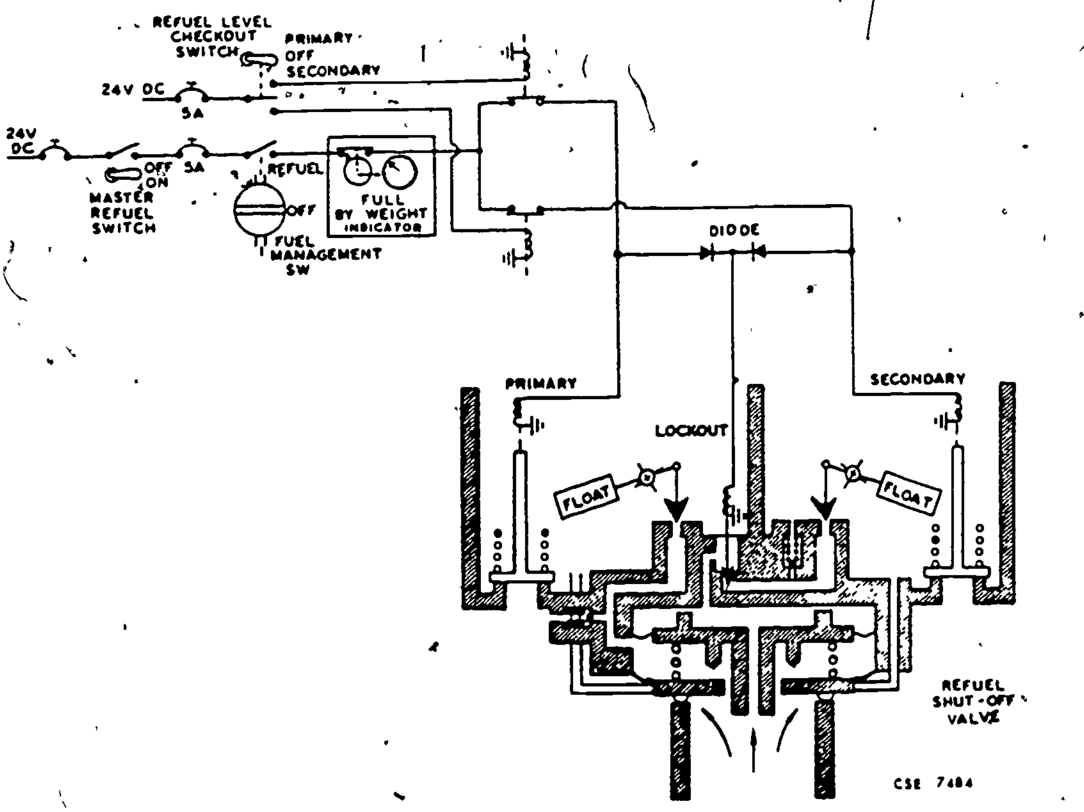

Figure 22. Fuel level control.

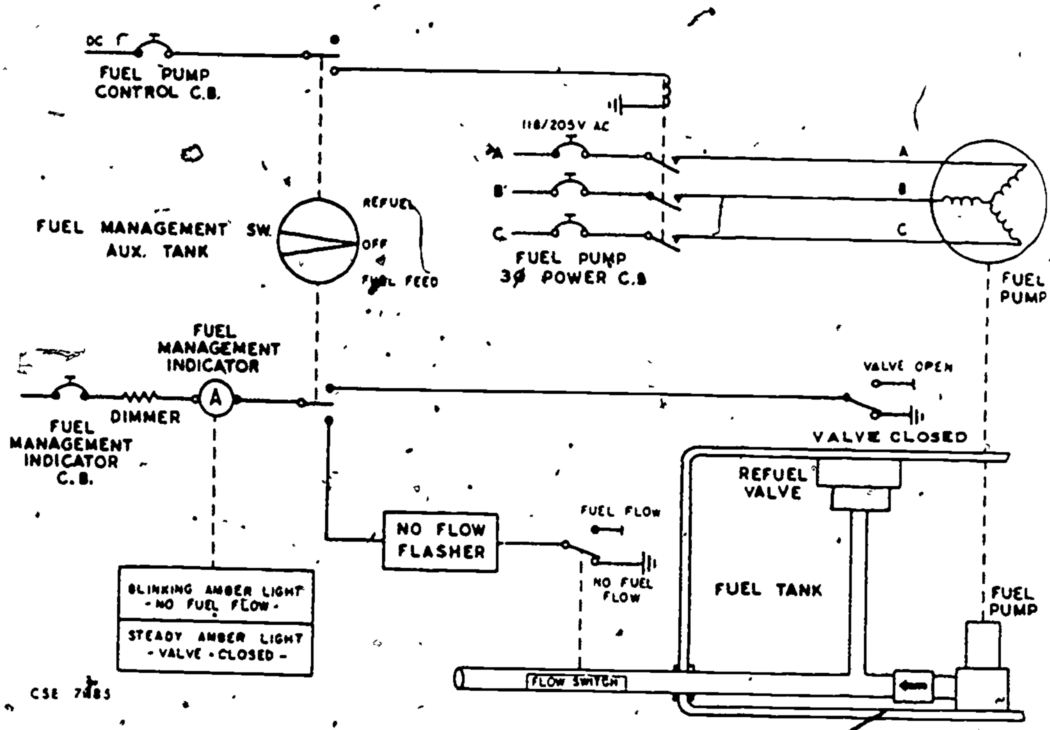

Figure 23. Fuel flow indicating system.

are actuated at the same level. Hence, the valve is dual-float but not dual-level actuated. When the fuel level control valves are closed by float actuation, the tank is full by volume; however, such a condition may never occur, depending upon the temperature and density of fuel being loaded. All fuel level control valves are connected in series with a switch located in the fuel quantity indicator for that tank between the valves and electrical power source. When the fuel quantity indicator pointer for any tank reaches the red line, the switch opens, causing the affected tank valves to close.

10-14. *Fuel flow indicating system.* A fuel flow indicating system (see fig. 23) provides an indication of no fuel flow for each auxiliary fuel tank by flashing the associated amber fuel flow indicator light on the fuel system panel. The system consists of a fuel flow indicator switch and an amber indicator light for each auxiliary tank and an eight-channel electronic flasher The indicating system is energized by placing the corresponding auxiliary tank fuel flow control switch to the FUEL FEED position.

10-15. The fuel flow indicator switch is line mounted in the fuel manifold for each auxiliary tank. Since the manifolds are routed through the fuel tanks or cells, the switches operate submerged in fuel. The flow indicator switch incorporates a swing flapper which permits fuel flow in both directions for fuel feeding or refueling. When fuel flow causes the flapper to be moved in the direction of pump discharge flow, a normally closed microswitch is opened. When the flapper is in the vertical no-flow position or when it is moved in the direction of refuel flow the microswitch remains closed and provides a ground circuit for the associated channel of the no fuel flow flasher unit. As the boost pump discharge flow increases, the swing flapper should cause the microswitch to open at a flow rate above 800 pounds per hour and close at a flow rate below 800 pounds per hour.

10-16. An eight-channel electronically controlled no fuel flow flasher indicates fuel flow conditions in the auxiliary fuel system. When a no-flow or reverse-flow condition exists, the no-flow indicator switch provides a ground circuit to a channel of the electronic flasher. As a result, the flasher provides an intermittent ground for the amber fuel flow indicator light on the fuel system panel adjacent to each auxiliary tank fuel quantity indicator. If a channel of the flasher is energized by placing the corresponding auxiliary tank fuel flow control switch to FUEL FEED position, the intermittent ground provided by the flasher will cause the indicator light to cycle ON and OFF at a rate of 40 to 100 times per minute. When normal fuel flow is resumed, the fuel flow indicator switch removes the ground signal from the flasher channel, and the channel returns to the monitoring condition.

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10-17. A dual-purpose fuel flow indicator amber light for each auxiliary tank is located on the fuel system panel adjacent to the associated fuel quantity indicator. The light flashes to indicate a no-fuel flow condition during fuel feeding and glows steadily to indicate closed fuel level control valves during refueling. Brightness of the indicator light is controlled by the dimmer control unit Nr. 2. The auxiliary tank fuel flow control switch energizes the no-flow indicating circuit when placed in FUEL-FEED position and activates the fuel level control valve closed indicating circuit when placed in REFUEL position.

10-18. *Boost pump pressure checkout system.* The boost pump pressure checkout system provides a means of ground checking individual boost pumps in both the main and auxiliary tanks to be sure that the pump discharge pressure at no-flow is within the permissible range. The system consists of a green indicator light, a control switch, and a press-to-relieve switch on the fuel system panel and a pressure checkout pressure switch, a solenoid valve, and a check valve. The electrical schematic for the system is shown in figure 24. Since the boost pump pressure checkout switch samples pressure from the engine fuel crossfeed manifold, pressure from the boost pump to be checked must be routed to the crossfeed manifold by opening the required control valves. Individual boost pumps are checked by pulling and resetting the boost pump control circuit breakers.

10-19. A dual-pressure switch contains two independent switches which are actuated at different fuel pressures by a single diaphragm. The switch for the main tank boost pump is set to close the circuit to the green pressure checkout indicator light on the fuel system panel at 10 (± 1) psi fuel pressure and to open when the pressure drops to 6 psi. The switch for the auxiliary tank boost pumps closes at 24 (± 1) psi and opens at a minimum pressure of 19 psi.

10-20. A three-position toggle switch on the fuel system panel may be positioned to select and energize the desired microswitch in the dual pressure switch. The switch has MAIN, OFF, and AUXILIARY positions. In the MAIN position the indicator light is controlled by the low pressure (10 (± 1) psi) switch and is used while checking the discharge pressure of the main tank boost pumps. In AUXILIARY position the high-pressure (24 (± 1) psi) switch is used to check the discharge pressure of the auxiliary tank boost pumps. When the switch is in the OFF position, the checkout system is deenergized.

10-21. A solenoid type drain valve is used to relieve the pressure in the crossfeed manifold after the checkout of each pump (see fig. 24). The 24-vdc solenoid valve is controlled by the press-to-relieve button on the fuel system panel. The solenoid valve control circuit is energized and protected by the fuel pump pressure checkout circuit breaker. When the press-to-relieve button is pressed, the solenoid valve opens; and fuel from the crossfeed manifold is routed through a check valve into Nr. 2 main tank.

10-22. *Wing tanks level warning system.* A red indicator light located adjacent to each external tank fuel quantity indicator is provided to warn the pilot of an unsafe level of fuel in the

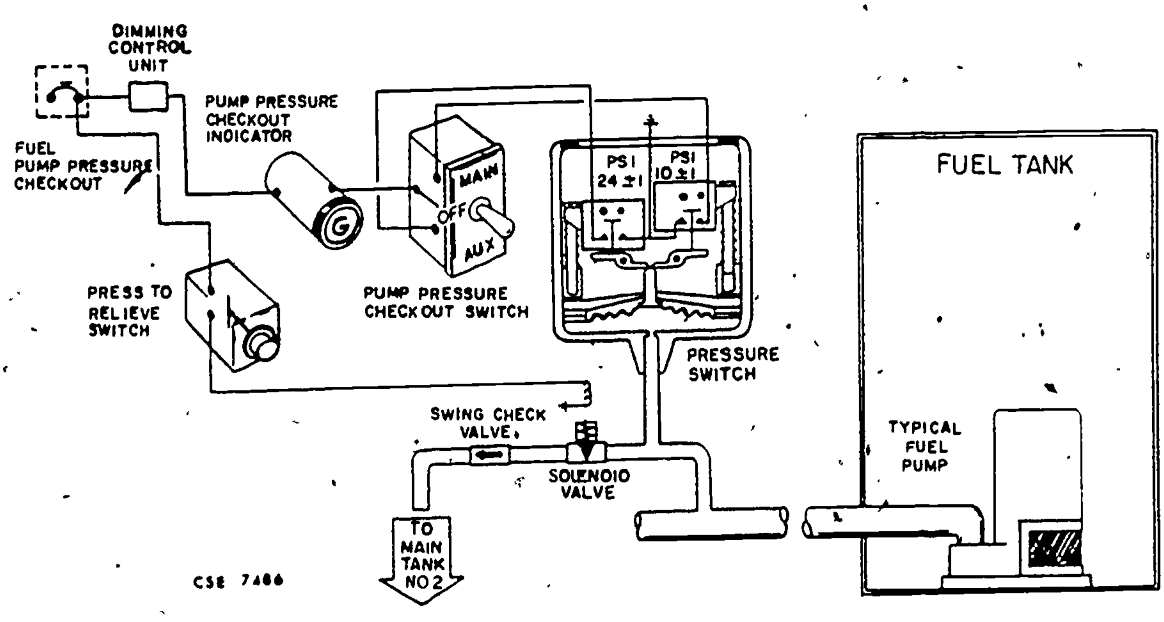

Figure 24. Fuel boost pump pressure checkout system.

outboard wing and/or external tanks. The indicating system is controlled by cam-actuated safe level switches contained within the fuel quantity indicators. The switches for the external and outboard wing tanks open the electrical circuit when the fuel quantity in the tanks is above safe level. The switches (for the main tanks) close the electrical circuit when the fuel level in the Nrs. 1 and 4 main tanks is above 30 percent of tank capacity and the level in Nrs. 2 and 3 main tanks is above 50 percent of tank capacity. A green band on the main tank's fuel quantity indicators designates the range at which the safe level switches open the electrical circuit. Operation of both the left and right wing tank level warning lights is identical. For example, power to the left wing tank level warning light is routed in parallel through the safe level switches in the fuel quantity indicators for the external and outboard wing tanks and through the auxiliary tank fuel control switches Nrs. 17 and 18 when in the FUEL FEED position. After passing in parallel through these four components, the power is routed in parallel through the safe level switches in the Nrs. 1 and 2 main tank fuel quantity indicators and to the left red indicator light. Since power must pass through one of the main tank fuel quantity indicators, the red warning light cannot glow under any condition when both indicators are in the safe level (green band) range. With the main tanks serviced above the safe level range, the red warning light will glow to indicate an unsafe fuel load (if the external and outboard wing tanks are not serviced to a safe level). The red warning light will glow to indicate unsafe fuel use if either the external tank or the outboard wing tank fuel control switch is placed in FUEL FEED position while the Nr. 1 or 2 main tanks contain fuel above safe level. Operation of the right wing tank level warning light is identical.

10-23. **Operation.** Basic fuel system operation is pretty much the same for all types of aircraft. It is a matter of understanding the correct sequence of operation for each particular type of aircraft. In this section of this chapter we will discuss various subsystem operations. This discussion will provide you with the knowledge necessary to determine if the system is functioning correctly.

10-24. *Engine feed circuits.* External power should be connected to the aircraft and engines 1 and 2 started. Main tank Nr. 1 toggle switch is placed in the ON position. All four boost pumps in tank Nr. 1 start and supply fuel to engines 1 and 2.

10-25. Fuel will be fed directly from the aft body tank to engines 1 and 2 by the use of the following procedure. Locate switch Nr 28 on the fuel management panel (see fig. 21). On the face of the switch is an arrow. Place the switch so that the arrow points away from the fuel quantity indicator for the aft body tank. As the switch is turned, the boost pumps in the aft body tank will start and supply fuel pressure to valve Nr. 13. Place switch Nr. 13 so that the white line on the face of the switch lines up with the white flow line on the fuel management panel. Fuel will now be fed from the aft body tank to engines 1 and 2. When switch Nr. 13 is turned, two boost pumps in the main tank will be deenergized.

10-26. As the fuel supply in the aft body tank begins to run low, the amber light next to its fuel quantity indicator will begin to flash. This tells the crew that the aft body tank is no longer feeding fuel and should be turned off. and a new tank selected to feed fuel to the engines.

10-27. At this point fuel will be fed from the forward body tank to engines 1 and 2. Locate switch Nr. 25 and turn it so that the arrow points away from the tank. This will cause pumps in the forward body tank to start pumping fuel. Follow the flow line down to switch Nr. 29. This switch must be turned so that the line on the face of the switch lines up with the flow line on the management panel (see fig. 21). This will cause valve 29 to open and allow fuel to be fed to engines 1 and 2 through valve Nr. 13, which is already turned to the OPEN position. When the forward body tank fuel flow drops below 800 pounds. the amber light for the forward body tank will flash, indicating that the tank is no longer feeding fuel, and switch Nr. 25 should be turned off.

10-28. Fuel should not be fed from the outboard wing tanks or external tanks unless the main tank quantity indicators are in the green band range. If fuel is pumped from these tanks with main tanks above the green range, the red wing tank warning light will come on, indicating an unsafe wing loading condition. This condition can also be caused during the refuel operation. From this explanation it can be seen that fuel can be routed many ways depending on the position of the switches located on the fuel management panel. It will be necessary to use the TO when working on the fuel system for information as to component operation and wiring data.

10-29. *Single-point refueling circuits.* When the aircraft is to be refueled on the ground, the single-point refueling receptacle located in the left forward wheel well is used. With a fuel line connected to the receptacle, the master switch is placed in the ON position and the refuel valve control switch is placed in the OPEN position. (See fig. 21.) This will allow fuel under pressure to enter the refuel manifold. Switch Nr. 29 must

now be placed in the OPEN position (white line on the face of the switch must line up with the fuel flow line on the management panel) so that the left wing and aft body tanks can be refueled. Assume that main tank Nr. 1 is to be refueled. Switch Nr. 19 must be turned to aline the line on the switch with the fuel flow line on the management panel. This will allow fuel flow control valve 19 to open and cause fuel flow to tank Nr. 1.

10-30. When switch Nr. 19 is operated, power will be applied from the master refuel switch through switches Nr. 19, then through the fuel quantity indicator, to energize the primary and secondary solenoids in the fuel level control valve, allowing it to open. (See fig. 22.) At the same time, a circuit will be completed through switch Nr. 19 to the amber light. With the valve open and fuel flowing through the valve into the tank, the amber light will be out. As the tank reaches the full mark, the floats will close their respective ports and fuel pressure will close the valve. The amber light will come on, indicating to the crew that tank Nr. 1 is full and that switch Nr. 19 should be closed. The amber light for the main tank does not flash at any time.

10-31. To refuel an auxiliary tank, place the switch for the tank to be refueled so that the arrow on the switch points to the quantity indicator for that tank. (See fig. 21.) When the auxiliary tank is full, the valve will close and the amber light will come on, indicating that the tank is full and that switch for that tank should be turned off. It must be remembered at this point that the fuel level control valve will close as a result of a definite weight or volume of fuel and cause the amber light to come on.

10-32. *Fuel level control valve checkout circuit.* With the master refuel switch in the ON position, locate the refuel level checkout switch on the same panel, place it in the PRIMARY position, and with fuel pressure in the manifold, select tank Nr. 2 and place switch Nr. 20 in the OPEN position. This will cause the primary chamber to flood. The float will then close its port, and fuel pressure will close the valve. The amber light will come on, indicating that the primary side of the valve checks correctly. (See fig. 22.) To check the secondary side of the valve, place the refuel level checkout switch in the SECONDARY position. This will cause the secondary chamber to flood. The secondary float will close its port and cause the fuel pressure in the manifold to close the valve. Again the amber light will come on, indicating that the secondary side of the valve is correct.

10-33. When external fuel pressure is used to perform the fuel level control valve checkout, it will be necessary to place the refuel valve switch in the OPEN position. The fuel flow control switches for the external and outboard wing tanks have spring-loaded guards to secure the switches in the OFF position and prevent inadvertent operation. This is necessary because the fuel load in these tanks affects wing loading.

10-34. *Boost pump pressure checkout circuit.* The fuel system is provided with a boost pump pressure checkout circuit to determine that the pump discharge pressure at no-flow for the main tank and auxiliary tank boost pumps is within permissible range. The control switch for the pressure checkout circuit is located on the copilot's side of the forward instrument panel. The switch is a three-position toggle switch marked "MAIN," "OFF," and "AUX." The control switch for the solenoid valve marked "PRESS TO RELIEVE" is located on the copilot's side of the forward instrument panel. The green pressure check light is located next to switch Nr. 10 on the fuel management panel and is marked "PUMP PRESSURE CHECKOUT."

10-35. When the pump pressure checkout switch is placed in the MAIN position and the circuit breakers for pumps 4, 6, and 7 are opened, then the control switch for tank Nr. 1 should be placed in the ON position and switch Nr. 10 placed to the OPEN position. If pump Nr. 5 is putting out its rated pressure, the green light will come on (see fig. 23).

11. Air Refueling Circuits

11-1. Many USAF aircraft are provided with an air refueling system to permit takeoffs with smaller gross weights, and once airborne, to extend the range of operation by replenishing the fuel tanks from a flying boom-equipped tanker aircraft.

11-2. **System Components.** The air refueling system consists of a signal amplifier, control panel, control switches, emergency disconnect switches, three indicator lights, slipway lighting systems, and an air refueling receptacle. The air refueling system can be operated manually or automatically by the pilot or copilot.

11-3. The signal amplifier is the heart of the air refueling circuit, and is actually an electronic three-position switch. Each time a signal is sent to pin F of the amplifier, it switches to the next position. The three positions are READY FOR CONTACT, CONTACT MADE, and DISCONNECT.

11-4. The induction coil, located in the air refueling receptacle, couples the receiver aircraft signal circuit to the tanker aircraft signal circuit. Any disconnect signal from the tanker or receiver aircraft will be transferred through the induction coil, and an automatic disconnect will take place.

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11-5. The slipway door control valves are solenoid-actuated hydraulic valves. The valves control the slipway door hydraulic actuators. The normal slipway door control valves receive hydraulic pressure from the left body hydraulic system. The alternate slipway door control valves receive hydraulic pressure from the right body hydraulic system.

11-6. A solenoid-operated slipway drain valve is provided for the drainage of residual fuel after air refueling is accomplished and the slipway doors are closed. When the slipway doors are closed and the air refueling relay is deenergized, the drain valve opens and drains residual fuel from the slipway and receptacles.

11-7. The two toggle control valves are solenoid-operated and are mounted on the hydraulic panel located to the left of the air refueling receptacle. The normal toggle control valve is actuated by the air refueling circuit, and the alternate toggle control valve is actuated by a manually controlled toggle latching switch on the air refueling panel.

11-8. A fuel pressure disconnect switch, located in the cabin refuel manifold scavenge system sealed box at the single-point refueling receptacle, is accessible from the forward wheel well. The pressure switch provides a disconnect signal to the signal amplifier and the tanker whenever fuel pressure exceeds 69 ± 3 psi. The switch is leak-proof and explosion-proof.

11-9. **Operation.** When the master switch is in the ON position and the slipway doors are closed and locked, the amber light (not shown) will be on. When the normal slipway door control switch is placed in the OPEN position and the signal amplifier power switch in the NORMAL position, power will be supplied to the OPEN solenoid of the normal slipway door hydraulic control valve and through the signal amplifier power switch to pin A of the signal amplifier. As the slipway door opens, the latch limit switches will actuate and the slipway doors CLOSED AND LOCKED amber light will go out. The normally open latch limit switches remove power from the slipway door relay and the amber light when the slipway doors open. The signal amplifier, energized through pin A, supplies voltage from pins C to the slipway door open limit switches, from pin E to the normally open toggle shaft limit switches, and from pin H to the normally open plunger limit switch. When the doors reach the fully opened position, the slipway door open limit switches (see figure 25) actuate and cause the READY FOR CONTACT blue light to come on. The air refueling system is now ready to receive the tanker boom.

11-10. When the tanker boom nozzle seats in the air refueling receptacle, the nozzle actuates the plunger limit switch, completing the circuit from pin H of the signal amplifier to the hydraulic toggle latching normal control valve and the CONTACT MADE green light. As the toggle shafts rotate to the boom latched position, the toggle limit switches are actuated. As a result, power is supplied from pin E of the amplifier through the actuated toggle limit switches to pin F on the amplifier. This places the amplifier in the contact-made condition, removing power from pins C and E, causing the READY blue light to go out. In the contact-made condition, the signal amplifier supplies voltage from pin J to one toggle limit switch and from pin H through the plunger limit switch to the CONTACT green light. The boom is now in place, and fuel can be transferred from the tanker to the fuel tanks in the receiving aircraft.

11-11. A disconnect signal to pin F of the signal amplifier can be caused by any one of the following conditions:

- Actuation of the disconnect switches on the pilot's or copilot's control wheel.
- Actuation of a disconnect signal by the tanker boom operator through the signal coil in the refueling receptacle.
- Excessive fuel pressure in the refuel cabin manifold, which causes the pressure disconnect switch to actuate.
- A break in contact between the boom nozzle and receptacle, causing the toggle shafts to rotate and actuate the toggle limit switch to the unlatched position.
- When excessive movement of either the receiver or tanker aircraft causes the tanker boom to exceed envelope limits, a disconnect signal is initiated by the tanker signal system.

11-12. When a disconnect signal is received at pin F of the signal amplifier, the amplifier is placed in the disconnect position and the DISCONNECT amber light will come on. Power is removed from pin H, deenergizing the toggle normal control valve, and the CONTACT green light will go out. With the toggles released, the disconnect signal, transferred to the tanker through the induction coils, causes the tanker refueling boom to retract and the disconnect is completed.

11-13. Momentarily pressing the signal amplifier reset button on the air refueling panel removes power from the signal amplifier and places the amplifier in the ready-for-contact condition. The DISCONNECT amber light will go out and the READY blue light will come on. The signal amplifier may also be returned to the ready-for-contact condition by placing the master refuel switch momentarily in the OFF, then back to the ON position.

11-14. After air refueling is completed and a disconnect has been made, the slipway doors are closed by placing the normal slipway door switch in the CLOSE position. When the doors

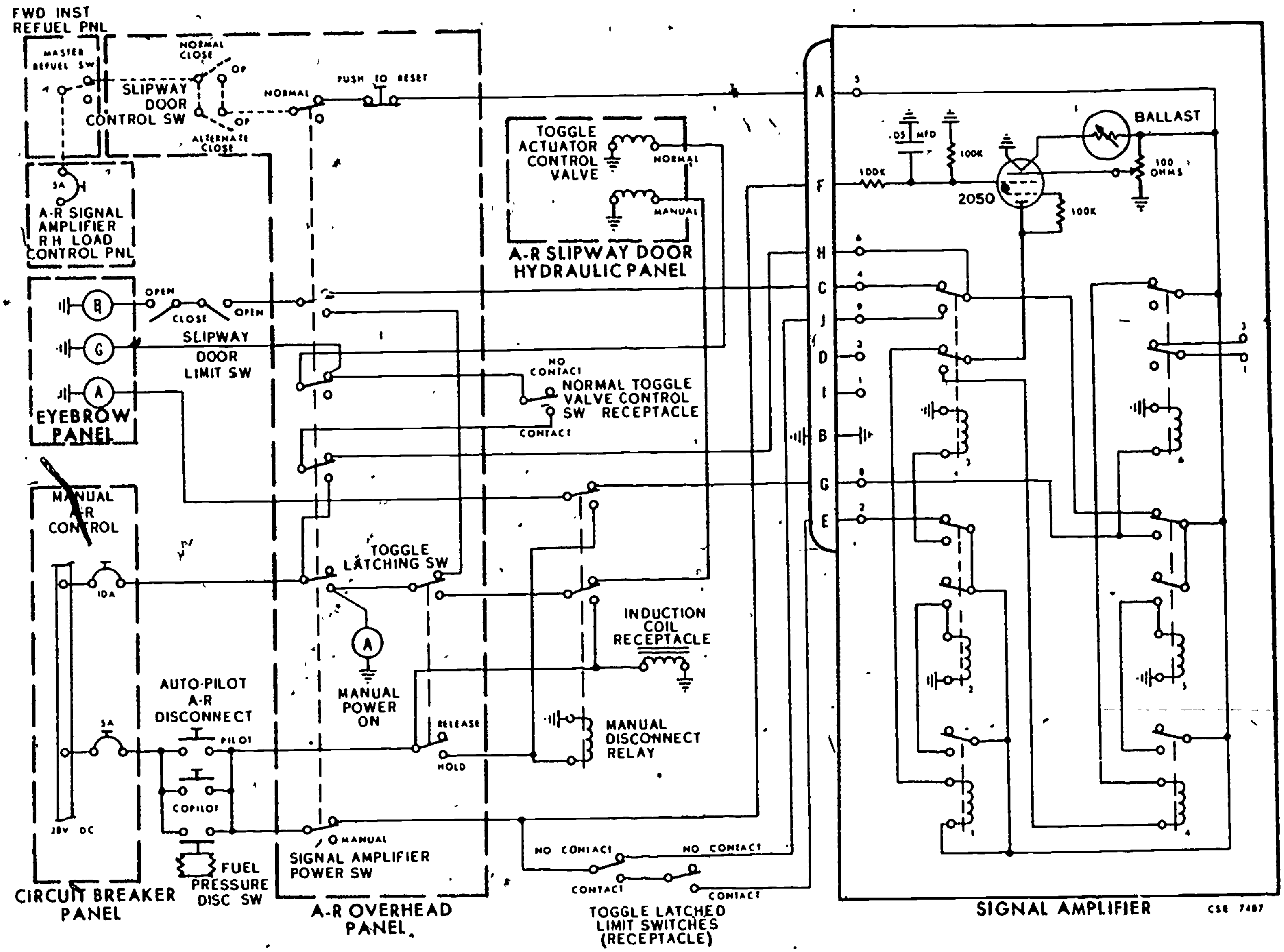

Figure 25. Air refueling control system.

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close and latch, the latch limit switches will actuate, energizing the slipway door relay and causing the SLIPWAY DOORS CLOSED AND LOCKED amber light to come on. The energized slipway door relay opens the holding circuit for the normal air refueling relay, deenergizing the close solenoid of the slipway door control valve. When the master refuel switch is placed in the OFF position, power is removed from the air refueling control panel, and the SLIPWAY DOORS CLOSED AND LOCKED amber light will go out.

12. Fuel Scavenge Circuits

12-1. Two separate fuel scavenge systems are provided to remove fuel trapped in the refuel (cabin) manifold and main manifold after the aircraft has been refueled either by air refueling in flight or single-point refueling on the ground. The cabin manifold is forward of the refuel valve, and the main mainfold is aft of the refuel valve. Scavenged fuel from the cabin manifold is returned to main tank Nr. 2, and main manifold scavenged fuel is returned to main tank Nr. 3.

12-2. **System Components.** The scavenge systems consist of a scavenge pump, shutoff valve, float switch, and a control switch and amber indicating lights located on the copilot's side of the forward instrument panel.

The scavenge pumps are 115-vac capacitor motor-driven pumps with output of approximately 2 gallons per minute. The scavenge pump for the cabin manifold is located inside the scavenge system box which surrounds the single-point refueling receptacle in the forward wheel well. The main manifold scavenge pump is located below the center wing tank in the forward side of a fuel and vaportight equipment shroud.

12-3. Each fuel scavenge pump is controlled directly by a float switch located in the scavenge drain line. The float switch is an inclosed unit containing a magnetic type float in a fuel chamber and a single-pole, double-throw, normally open switch in the sealed upper chamber. When the switch closes, the pump control relay should be energized and the scavenge pump will operate, provided the fuel scavenge control switch is in either CABIN or MAIN position.

12-4. The cabin manifold shutoff valve is located downstream of the float switch in the scavenge drain line. The valve is a normally closed, solenoid-operated, gate-type valve. Operation of the valve is controlled by the adjacent float switch.

12-5. The main manifold shutoff valve, located upstream of the float switch, is a normally closed, solenoid-operated, shuttle-type valve. The valve will open when the scavenge system control switch is moved to the MAIN position regardless of the float switch position.

12-6. **Operation.** The scavenge system control switch is a three-position switch. Three positions are CABIN, OFF, and MAIN. Placing the switch in the CABIN position should produce no results whatsoever, unless the refuel manifold scavenge float switch contains fuel. If the float switch contains fuel, moving the control switch to the CABIN position should energize the refuel manifold scavenge shutoff valve. The amber FUEL IN MANIFOLD light adjacent to the control switch should come on when the manifold contains fuel (and the master refuel switch is in the OFF position), regardless of the control switch position. The shutoff valve should remain open, the pump should operate continuously, and the light should stay on as long as fuel is present in the float switch or until the scavenge system control switch is moved to the OFF position or the master refuel switch is placed in the REFUEL position.

12-7. When the scavenge control switch is placed in the MAIN position, the main scavenge shutoff valve should open regardless of the float switch, and the FUEL IN MAIN MANIFOLD light should come on regardless of whether the main manifold contains fuel or not. A few seconds later, if the main manifold contains fuel, the rising fuel in the float switch float chamber should cause the float switch to close, energizing the pump control relay which in turn will energize the interlock relay. When this occurs, the scavenge pump will operate continuously. The shutoff valve will remain open, and the FUEL IN MAIN MANIFOLD light should stay on until all fuel is removed from the float switch float chamber. When the float chamber is emptied, the float switch contacts will open, causing the pump control relay to be deenergized, the shutoff valve to close, and the FUEL IN MAIN MANIFOLD light to go out. The scavenge system control switch should be returned to the OFF position. To be sure the main manifold is completely scavenged, the scavenge system control switch should be returned to the OFF position to deenergize the interlock relay and then return to the MAIN position again to cause the shutoff valve to reopen. If the scavenge pump is energized by this action, the pump is pumping fuel away from the float switch faster than gravity flow can refill the float switch float chamber.

12-8. The same condition may exist in the cabin refuel manifold scavenge system; however, the recycling will probably occur automatically provided the scavenge system control switch remains in the CABIN position. In either scavenge system recycling is undesirable, and the source of difficulty should be located and corrected.

Power Plant and Related Control Circuits

THE POWER PLANT is a very important part of the aircraft. Without it the aircraft would never leave the ground. The more you know about the power plant the easier your job will be to maintain the systems you are responsible for. We do not intend to make an engine mechanic out of you. However, we would like to equip you with enough knowledge to be an outstanding electrician.

2. To start an engine, electric power is needed. Both the starter and ignition system depend on sufficient electric power at the correct time. Once the engine is running, certain conditions must be maintained; these will be our major concern in this chapter.

3. Points of discussion will include the starter systems, auxiliary components, ignition systems, and some related power plant control systems. A thorough knowledge of the systems covered in this chapter will make you a better electrician. This is what the Air Force is looking for. To get things started we will discuss the starter system.

13. Starter Systems

13-1. If you study your job description in AFM 39–1, you will learn that you are required to maintain and repair starter systems and components. This means that you must be completely familiar with the operation of both dc and ac starters as well as fuel-air and pneumatic starters. Since it is very probable that you will be required to work on jet engine systems, this chapter will give you the knowledge necessary to troubleshoot or perform operational checks on a variety of jet engine systems.

13-2. Your duties as an aircraft electrician also require you to maintain starters and actuators. You must be able to test these units after overhaul or repair, so you must be familiar with the procedures to be followed in using the test equipment. Let us start the discussion with dc starters.

13-3. **DC Starters.** As you learned earlier in this volume, a motor is a device that changes electrical energy into mechanical energy. Now, let's see how dc motors are used with engine starters.

13-4. Direct current starters use series motors because they have high starting torque. You will recall that series motors are advantageous for applications in which there can be widely varying loads and extreme speed changes. In case your memory needs refreshing, let us briefly review a few facts about series-wound dc motors. You will see immediately how well suited they are for use as starter motors.

13-5. In the series group, as you recall, the field and the armature are connected in series and the same current passes through both. This last point is an important one to remember. If the load causes a change of current through the armature, it also affects the current in the field coils. Up to the point of saturation of iron, the field flux is almost directly proportional to the armature current. The equation for torque is:

$$T = KI^2$$

(T stands for torque, K for circuit constant, and I for the armature current). Thus, in a series motor the torque produced is proportional to the square of the armature current: if the armature current is doubled, the torque is quadrupled. For example, if the torque is 40 foot-pounds at 25 amperes, at 50 amperes it would be 160 foot-pounds. From this simple problem you can note that because the torque rises very rapidly as the current increases, a series motor is particularly useful when a high starting torque is required. How do these facts apply to turning an engine?

13-6. As the motor starts, before it has built up any cemf, the current is high and so is the resulting torque just at the same time it is most needed. However, it should be pointed out that armature reaction and saturation of the iron both tend to prevent the torque from increasing as rapidly as the square of the current, as shown in the torque curve in figure 26. To take just one example of the figure, observe that if you check the torque at 5 amperes, you find it to be 3.5

foot-pounds. But at 10 amperes the torque is 12 foot-pounds instead of having quadrupled to 14 foot-pounds.

13-7. So much for the torque. But how about the speed of a series motor? How is it going to be affected by the varying field flux? For the answer, it is necessary to review a few points about electric motors. If the load on a series motor goes up, so does the current flow through it. To allow this additional current to flow, the motor cemf must go down. If—and that is a big IF—the field flux remained constant, the necessary decrease in cemf could be brought about by a slight reduction in speed, as is the case with the shunt motors. The flux, however, does not remain constant but increases almost proportionately to the armature current. That is, if you double the load, you practically double the field flux. Hence, you must decrease the speed still further to make up for this increase in flux.

13-8. On the other hand, as the load on a series motor is reduced, the field flux decreases. The motor speed must now increase in order to generate the required cemf. Therefore, when there is no load on the series motor and the field flux is very low or almost zero, the speed rises to a dangerous point. In fact, the motor may be damaged if it runs so fast that the armature coils are thrown out of their slots in the armature.

13-9. Because an unloaded or lightly loaded series motor may virtually run away from itself, it is always connected to its load by a shaft or gears. When testing a series-wound motor without the normal load of a gear train, always use one-half of its normal rated voltage, or less, as specified in the pertinent technical order. We should add one more point while we are still on the general discussion. Since large currents are encountered in the operation of series motors, all their energizing circuits are handled through a B–8 type solenoid.

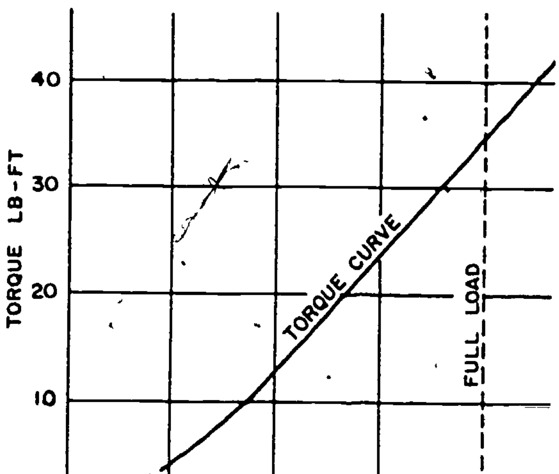


Figure 26. Torque curve.

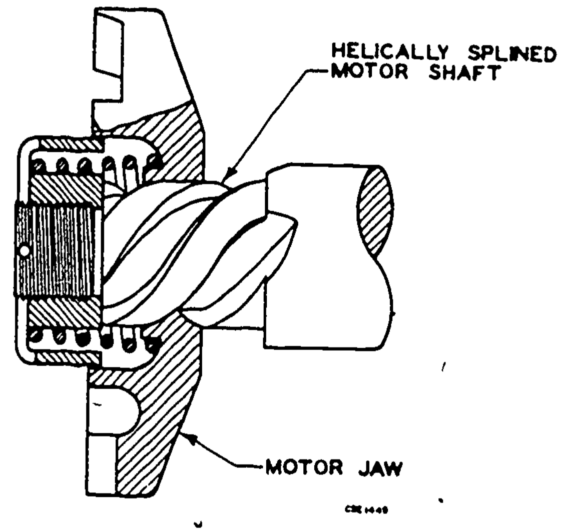


Figure 27. Jaw type engaging mechanism.

13-10. Much of the preceding introductory material to dc starters has been a review. The chief purpose is to fill in any needed gaps for the specific discussion and to show why series motors are well adapted for use in starter systems. Now we may turn our attention to the methods used to engage a starter to the reciprocating engine.

13-11. *Jaw type engaging mechanism.* With this design, when the motor is energized, it is engaged directly to the flywheel by a movable jaw located on a helically splined shaft at the power output end of the motor. (See fig. 27.) When the motor armature starts to rotate, the starter jaw will tend to remain at rest. As the motor shaft turns, the motor jaw will move forward along the shaft until it engages a corresponding jaw on the flywheel. When the energizing current is removed from the motor, the motor jaw starts to slow down, whereas the stored energy in the flywheel tends to keep it rotating at a high speed. As a result, the two jaws are mechanically disengaged and a spring, which was compressed as the motor jaw originally moved forward, forces the motor back to its rest position on the shaft.

13-12. One of the most common troubles with this type of mechanism is that the motor jaw sometimes binds on the armature shaft and will not engage the flywheel jaw. Consequently, personnel often allow the motor to "race." As a result of energizing the starter while the flywheel is still turning, excessive damage, principally shearing, may occur to the teeth of the jaws.

13-13. *Roller clutch engaging mechanism.* In

this arrangement, the starter motor is engaged to, and disengaged from, the starter flywheel by means of a roller clutch that fits snugly inside the flywheel, as shown in figure 28. As you can note in the drawing, a slight rotation of the motor shaft forces the rollers of the clutch out against the inner surface of the flywheel. The latter is equipped with a hard steel insert. Whenever the motor rotates more slowly than the flywheel, the rollers are freed and the motor is automatically disengaged. If the aircraft is equipped with this mechanism, you do not have to wait for the flywheel to come to a stop before reenergizing the starter motor.

13-14. **Fuel-Air and Pneumatic Starters.** Some jet aircraft use special starters that operate on both fuel and air, or air alone for engine starting. In effect, this means that the aircraft is not dependent on external sources of air for starting the engines. These starters are so designed that they may be used as self-contained units, or may be used as conventional pneumatic starters. Let us start the discussion with the fuel-air type starter.

13-15. *Fuel-air starter.* The fuel-air starter is a small jet engine which is used to energize the turbine discs. The starter burns jet fuel in an integral combustion section and utilizes the energy released in combustion to drive a turbine. The latter, through a gear reduction clutch arrangement, drives an output shaft. The unit is designed to produce the torque required to accelerate a turbojet or turboprop engine from rest to a speed of 2300–2500 rpm within a given time.

13-16. The starter is mounted on the engine so that the output shaft engages the engine starter drive. Fuel is taken from the engine supply; electricity for ignition and control components are supplied by the aircraft electrical system. The compressed air needed for starter operation is taken from either an air bottle installed in the aircraft or from an external source. The flow of air to the starter is controlled by a solenoid-operated air shutoff valve located in the air duct. This valve is controlled by a switch located in the aircraft cockpit. All other controls for the operation of the starter are mounted within the unit.

13-17. The starter accelerates the engine to 2300–2500 rpm (35-percent engine rpm), at which time a set of centrifugal type switches on the starter terminate the starter combustion. In the event the starter overspeeds and the centrifugal switches do not open, an emergency cutout switch on the turbine prevents the starter from exceeding 2800 rpm. The starter clutch arrangement consists of an overrunning-disengage sprag type clutch that disengages when the engine accelerates to a speed greater than that of the starter, and a slip type clutch which minimizes the initial torque shock on the drive coupling at the beginning of each starter operation.

13-18. The driving member of the clutch arrangement is geared to the starter mechanism, while the driven member is geared to the engine starter drive through a drive shear coupling. Thus, when engine starting rpm is reached and energy input into the starter is terminated, the starter mechanism coasts to a stop, while the member of the clutch which is connected with the engine continues to turn with the engine. The unit is equipped with a shear pin which is designed to shear under extreme torque conditions. The pin will prevent damage to the starter or to the engine. This concludes our discussion on the mechanics of the starter.

13-19. We mentioned earlier that some aircraft are equipped with an air bottle for starting. This type of installation has an air storage bottle with a solenoid-operated control valve installed on the outlet, and an electric motor-driven air compressor to charge the storage bottle. The bottle stores enough air for two or three starts of the fuel-air starter, depending on the initial charge and the ambient temperature. The compressor automatically recharges the bottle.

13-20. The air compressor circuit, shown in figure 29, consists of a motor-driven, piston-type, compounded air compressor; moisture separator; pressure switch; priority valve; cycling timer; heaters; check valve; and pressure-relief valve. The operation of the compressor is controlled by the pressure switch. When the air pressure in the bottle drops below 2800 ± 100 psi, the pressure switch closes and completes the circuit from the 115- to 200-volt ac bus to the compressor motor, thus energizing the three-phase compressor motor. The compressor motor will continue to operate until the pressure in the bottle reaches 3000 ± 100 psi. At this time the pressure switch opens and breaks the circuit to the motor. The air to the compressor is supplied from the aircraft pneumatic supply system manifold through the pressure regulator. The regulator maintains the pressure at approximately 16.7 psi. The suction relief valve in the compressor supply line insures adequate air supply to the compressor if the pressure in the supply line should drop below the ambient pressure.

13-21. Now notice the cycling timer. This unit opens the drain valve in the air moisture separator every 10 to 12 minutes to keep the system free of moisture. Also included in the circuit is a thermal switch, which is set at 40° F. When the temperature in the air moisture separator reaches 40° F., the thermal switch closes, completing the circuit from the 28-volt dc bus to the heater. This prevents freezing of any water that may collect

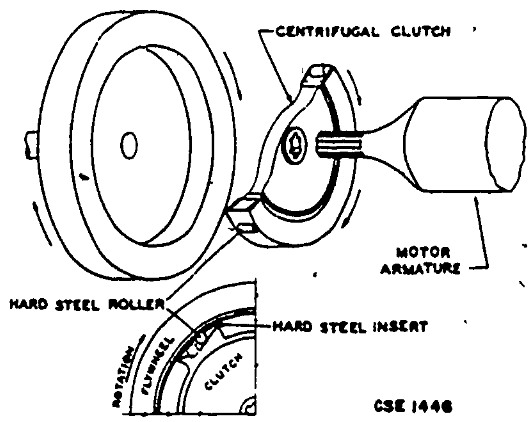


Figure 28. Roller clutch engaging mechanism.

in the moisture separator before the cycling timer operates. Now let's see how the starter system operates by examining figure 30.

13-22. The operation of the starter is automatically controlled by the units in the control box located on the rear of the starter. The items that are correlated through the control box, as shown in figure 30, are the time-delay switch, burner high-pressure switch, centrifugal switches, and the control relay.

13-23. To operate the starter, the ignition control and start switch must be placed in the GROUND START position; the fire switch should be in the NORMAL position. This will energize the fuel-air start power control relay. Power is now supplied to the starter control box. The control relay is energized by a 28-volt circuit, which is completed through the normally closed contacts of the pneumatic time-delay switch, and through the centrifugal cutout switches and the second set of contacts on the interlock relay.

13-24. When the control relay closes, power is supplied to the air supply solenoid valve, the fuel solenoid valve, and the ignition exciter, and through the third set of closed contacts on the interlock relay. At this time the fuel accumulator is opened by the air pressure from the starter line. Combustion then occurs, and a buildup of chamber pressure closes the low-pressure switch which removes the control of the system from the time-delay switch and also from one set of contacts of the interlock relay. After a period of approximately 1 second, the time-delay switch energizes the interlock relay. This turns off the ignition to the starter.

13-25. When the starter reaches cutout speed (2400 ± 100 rpm), the gear box centrifugal switch (also shown in fig. 31) breaks the control relay holding circuit and stops the starting cycle. This type of starter is critical on the starting limitations. The limits of temperature restrict the ability of the fuel-air starter to make repeated combustion starts. Normally, two start attempts within a ½-hour period will produce temperature approaching the maximum allowable value. If two starts are attempted within a ½-hour period, a third attempt can be made after a ½-hour cooling period provided 1650-psi air pressure is available. Successive start attempts may be made, provided a ½-hour cooling period follows each attempt. In the event you should want to cut the ½-hour waiting time, it is permissible if external cooling is used. The starter is cool enough for a start attempt if the bare hand can be held on the starter gearbox.

13-26. *Pneumatic starters.* Another type of starter you will no doubt have to work on is the pneumatic or pure-air starter, illustrated in figure 31. This starter is designed to provide the required torque and speed necessary to start a turbojet or turboprop engine. It is mounted on a specially designed pad. The starter output shaft is mechanically coupled to the jet engine starter drive. The starter is driven by compressed air, ducted through a combination pressure-regulating and shutoff valve to the starter inlet. This compressed air may be supplied from either ground-operated or airborne gas turbine auxiliary power units, or by air bled from the compressor of another engine in a multi-engine aircraft. The compressed air is supplied to the starter through a pressure-regulating and shutoff valve which will maintain the specified inlet air pressure.

13-27. When the engine starting speed is reached, the starter must be shut off and the drive disengaged. To accomplish this automatically, two centrifugal cutout switches (fig. 31) are included on each starter, one driven from the starter side and one from the engine side of the clutch. The cutoff switches include a set of flyweights driven by one clutch gear. These flyweights actuate a cutoff switch to break the circuit to the air start solenoid when the starter shaft speed reaches 3400 rpm. This shuts off the supply of air to the starter turbine, a spring disengages the clutch, and the turbine rotor stops rotating. The output shaft continues to run with the engine.

13-28. The starter control valve (valve actuator) is an air-operated butterfly valve, functioning as both a shutoff valve and a pressure-regulating valve. High-pressure air from an auxiliary air compressor, or compressor discharge air of another engine which is running, is connected to the pneumatic system pressure side of the starter. When the regulating and shutoff valve is closed, air can pass through the filter, the restrictor, and the pilot valve and is vented overboard to prevent the starter from operating.

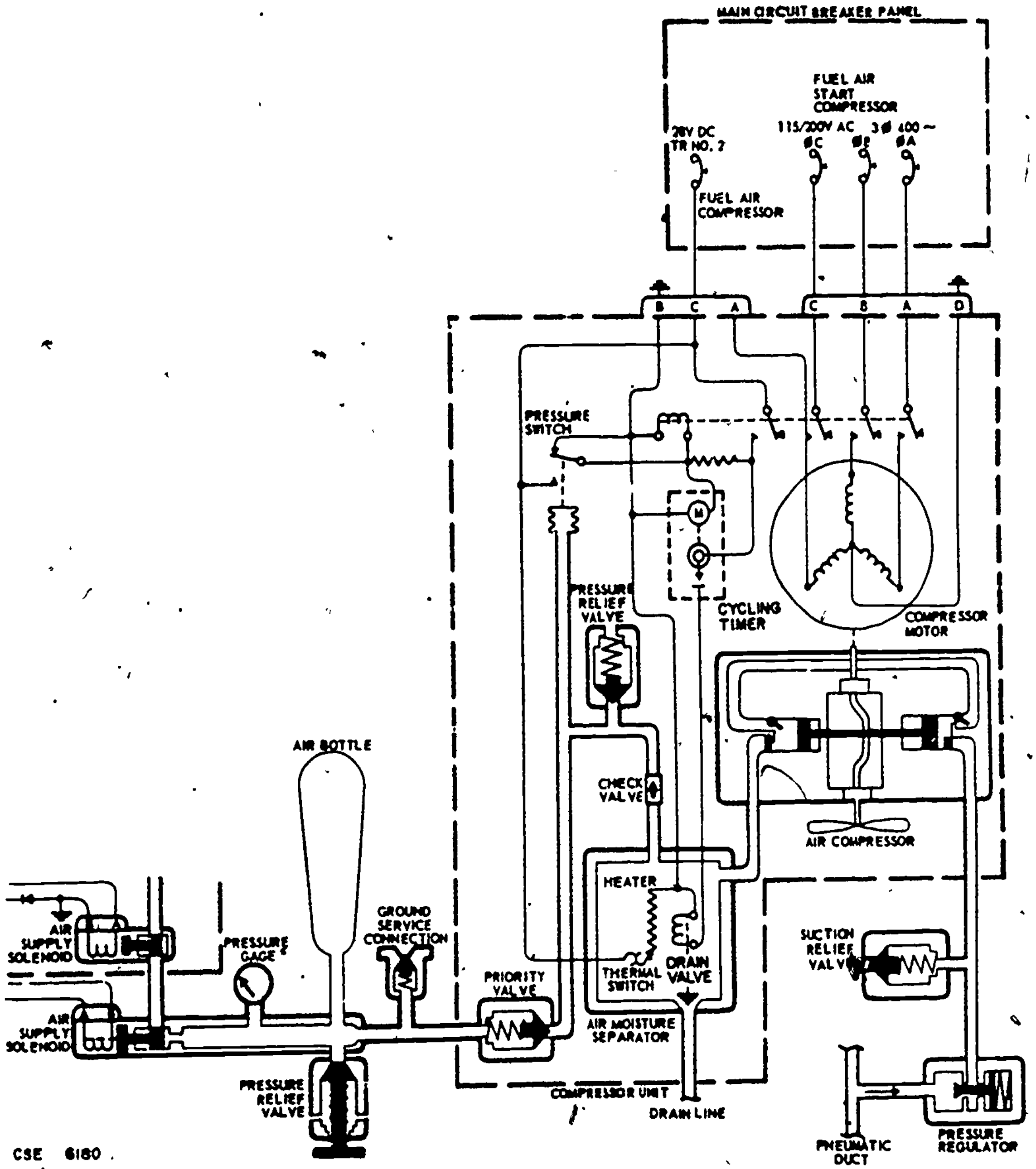


Figure 29. Air compressor circuit.

13-29. Now let's discuss how the starter operates. When the ignition control and start switch (as shown in fig. 31) is placed to the GROUND START position, the starter valve solenoid valve is energized, closing the air port of the pilot valve, thus allowing air to be vented to the top side of the valve actuator. Since this is called a helical cam, as the spring is depressed, it will open the regulating and shutoff valve. The air is thus directed from the pressure of the pneumatic system to the starter turbine wheel. The starter now is operating.

13-30. To keep the air pressure on the turbine wheel constant and to maintain the desired starter speed, a regulator valve is used. Notice that one end of the regulator is connected to the starter case and the other end is connected to the pilot valve by a mechanical linkage. If the pressure within the starter becomes too great, the pilot valve will allow part of the air to the actuator valve to be vented overboard. This, in turn, will close the shutoff valve and will stop the air flow to the starter.

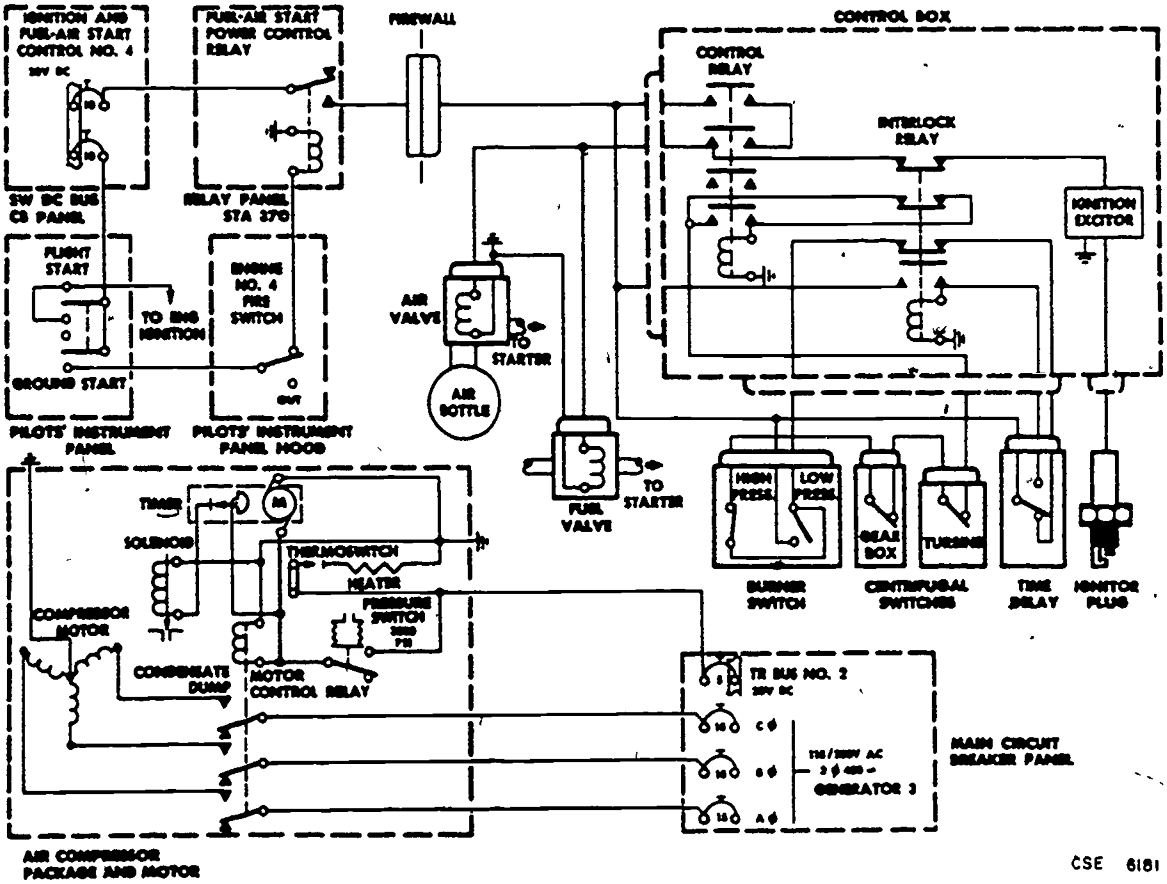


Figure 30. Fuel-air starter control system.

13-31. Another controlling device which is included in the starter consists of the centrifugal switches mentioned previously. When the starter speed has reached its maximum limit, the centrifugal switches break the ground circuit to the start relay. At the same time, the pilot valve opens, shutting off the air flow.

13-32. The starting limitations for the pneumatic starter vary with each manufacturer; however, you should never overoperate the starter. Most starters have 1½-minute maximum operating time, followed by 1- to 3-minute cooling period.

13-33. *Cartridge pneumatic starter.* The cartridge pneumatic starter provides a self-contained source of power for cranking jet engines to the high speeds necessary for starting. "Self-contained" means that the starter has the ability to start the engine without the support of ground equipment. The starter is essentially a gas-driven turbine wheel coupled to the aircraft engine through a reduction gear system and an overrunning clutch. The clutch disconnects the starter gear from the engine shaft, following a start, so that the engine will not drive the starter.

13-34. Energy for driving the turbine of the starter is supplied from any of three sources: expanding gases from the burning of a solid propellant charge, bleed air from an operating engine on the same aircraft, or low-pressure air from an external air source (such as an MA-1A trailer). Thus, the cartridge pneumatic starter offers the advantages of a self-contained system and the flexibility of the conventional low-pressure pneumatic starter discussed previously. Since you are already familiar with the operating characteristics of pneumatic starters, let us discuss the operation of a cartridge pneumatic starter.

13-35. A schematic of the starter is shown in figure 32. When the cartridge is ignited by the cartridge squib, the burning gases released by the cartridge flow into the turbine section of the starter, as indicated by the arrows. At the same time, air is drawn through the air inlet (dotted arrows) and mixed with the cartridge gas. As the turbine wheel is accelerated, its rotary motion is transmitted through the reduction gear train and the output shaft to the engine (see fig. 32).

13-36. Normally, when a cartridge is ignited, the energy from the cartridge is absorbed by the

aircraft engine. The starter produces torque until the cartridge is spent. When the cartridge is spent, the starter coasts to a stop and the engine, now at greater than self-sustaining speed, continues to accelerate to idle rpm. It should be noted that once the cartridge is ignited it will continue to burn, and there is no way to terminate the cycle. It is obvious, then, that various protective devices are necessary to protect the system from overspeed or overpressure conditions.

13-37. The safety disc, shown in figure 32, is located between the cartridge assembly and the exhaust of the starter and provides protection against overpressure conditions. Although the breech of the starter (the part that holds the cartridge) is capable of withstanding 3000-psig pressure, the safety disc is designed to rupture between 1600 and 2000 psig. When the safety disc ruptures, the cartridge gas is vented into the exhaust. Some of the gas is still applied to the turbine wheel, but the turbine wheel now produces less power and the engine may not start.

13-38. The pressure-relief valve, also shown in figure 32, provides protection during overspeed conditions of the starter. Overspeed of the starter is most commonly caused by a sheared shaft, but it may also be caused by a faulty cartridge that burns too rapidly. If the starter goes into an overspeed condition during the starting cycle (start switch on), the overspeed switch contacts of the overspeed governor close and complete a circuit to the pressure relief squib. When voltage is applied to the pressure-relief squib, the squib fires and ruptures the pressure-relief valve. This vents the cartridge gas to the exhaust of the starter and reduces the speed of the turbine wheel.

CAUTION: The pressure-relief squib should always be handled with extreme care. Wear safety glasses and gloves when handling the squib. Except when it is connected into the circuit, the leads of the squib should be shorted together to prevent inadvertent firing. The squib can be fired with approximately 0.5 ampere of current, and even a weak flashlight battery may contain enough power to fire the squib. If it is necessary for you to perform a continuity or resistance check of the squib circuit, be sure to use an ohmmeter with no more than 0.5 ampere output. A standard multimeter will fire the squib.

13-39. *Electrical system.* A schematic of the electrical system used with the cartridge pneumatic starter is shown in figure 33. When the

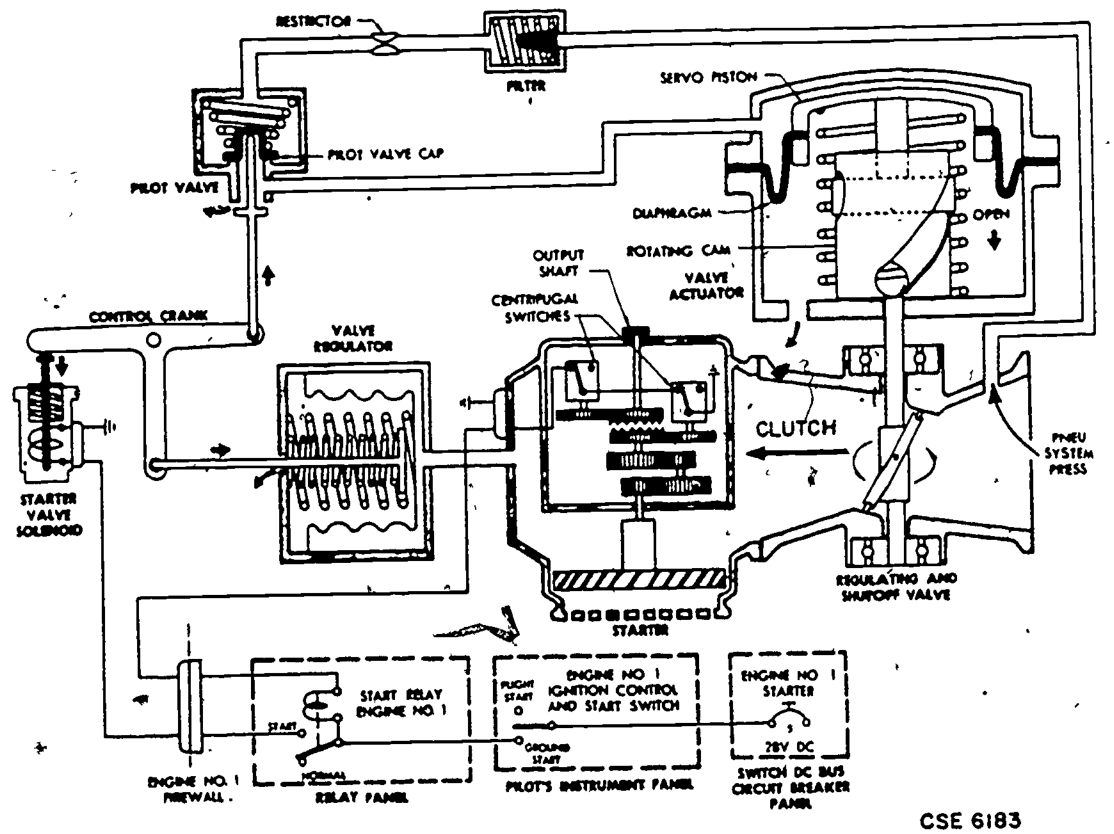


Figure 31. Pneumatic starter schematic.

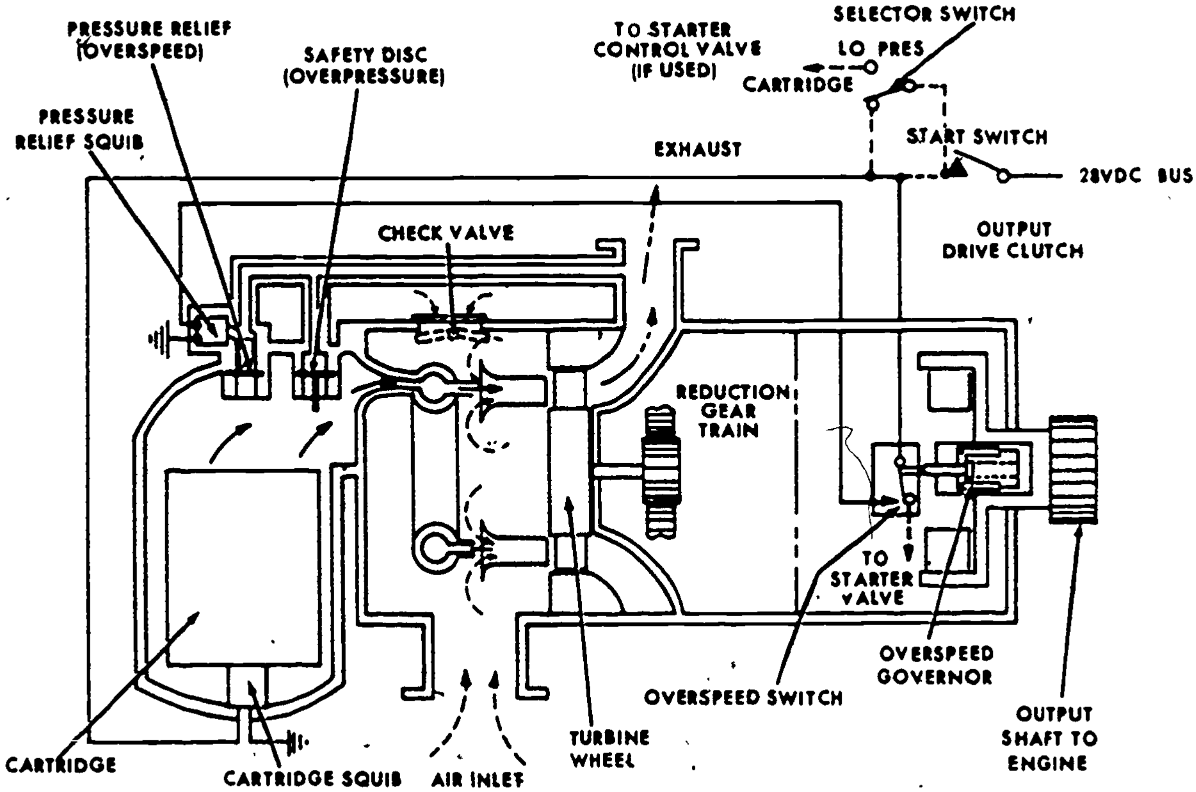


Figure 32. Cartridge pneumatic starter schematic.

start switch is moved to the start position, voltage is applied to the cartridge relay. When the cartridge relay energizes, the normally closed contacts CR1 open and the normally open contacts CR2 close. This completes a circuit through the 10-ohm resistor and the interlock switch (mounted in the breech assembly) to the cartridge squib. At the same time, the warning light illuminates. Note in figure 33 that the selector switch must be in the CARTRIDGE position to fire the cartridge squib. If the overspeed contacts should close, a ground is completed for the pressure-relief squib and the squib will fire if the start switch is ON and the selector switch is in the CARTRIDGE position.

13-40. When operating the starter for a cartridge start, it is very important that you be familiar with the operation of the starter. For example, the overspeed contacts close when the engine reaches a certain speed during the normal starting cycle. If the starter switch is closed at that time and the selector switch is in the cartridge position, the pressure-relief squib will ignite even though the turbine wheel is not in an overspeed condition.

13-41. The stop switch shown in figure 33 has no control of the starter once a cartridge start has been initiated; it is used only for terminating a low-pressure start in the event of trouble.

13-42. We have mentioned that the cartridge pneumatic starter can also be used to start an engine by using an external air source or by using the air bled from an operating engine on the aircraft. Both of these starting procedures are known as low-pressure starts. Low-pressure starts are also shown in figure 33. In this case the selector switch is placed in the LOW PRESSURE position. When the start switch is moved to the ON position, a 28-volt circuit is completed to the holding relay. When the holding relay is energized, the normally open contacts HR1 and HR2 close. The HR1 contacts form a holding circuit through the normally closed STOP switch so that the START switch need not be held closed. The HR2 contacts complete a circuit to the STARTER CONTROL VALVE, which opens to admit low-pressure air to the starter. When the starter reaches a certain speed, the overspeed switch closes, breaking the ground to the holding relay and terminating the starting cycle by deenergizing the holding relay. Note that in this case the pressure-relief squib does not fire. The start cycle may be terminated

at any time by opening the STOP switch. Whenever the holding relay is deenergized and no power is applied to the starter control valve, the valve closes and no air is supplied to the turbine wheel.

13-43. **Maintenance of Starter System Components.** The extent of maintenance that may be performed on reciprocating engine starters at field level is determined by the availability of special tools and test equipment. The maintenance of the motor section of the starter was discussed earlier and will not be discussed here. You will study starter maintenance in general plus the Prony brake, which is used to test starter performance and clutch settings. First let us discuss starter maintenance in general.

13-44. *Reciprocating engine starters.* As you perform your work, you will come across various starter designations. You should know something about the numbering of starters, so we will familiarize you with the subject in general. Keep in mind that on many starters the Air Force designation, such as J–1, G–6, G–18, and H–2. is stamped on the name plate, and that units with the same type number (G–18, for example) are interchangeable with one another. In addition to the type number, you will find the serial number, the manufacturer's part number, current draw, weight, operating voltage, and other pertinent information.

13-45. For example, consider the characteristics of starters designed and built by the Jack and Heintz Corporation, which are identified by a combination of letters and numerals, such as JH4PR. arranged as outlined in table 2. The symbols, whether letters or numbers, may appear in six distinct coding positions. Notice that one letter, L, is repeated, indicating one characteristic in position 3, another in 6. Further, as our example shows, some starter designations may not need a symbol in all 6 coding positions; observe that JH4PR does not include coding positions, 4 or 5.

13-46. The actual maintenance consists of inspection of the starter mount; checking for oil leaks around the mounting flange and brush length; and cleaning the brush boxes and the commutator. The instructions for cleaning are the same as those for generators. Recall that brush holders should be wiped with a cloth which has been moistened with an approved cleaning solvent and that burnt spots on the commutator should be sandpapered, followed by an airstream blast in the brush assembly to remove any loose particles.

13-47. The installation of starters involves several problems that are not experienced with other units discussed in this course. Before installing, make certain that the engine starter jaws are identical as to the number of teeth, size of jaw, and direction of rotation, as indicated by the slope of the teeth.

13-48. How is this done? First, remove the gasket and then measure the depth from the face of the mounting pad to the tip of the engine jaw teeth; likewise, determine the distance from the face of the mounting plate to the tip of the starter jaw teeth. When the jaw is retracted, a clearance between the teeth of the two jaws must be maintained for each installation. This clearance is specified in the applicable technical order for the aircraft. You should always refer to those publications to learn the amount of clearance required for the aircraft with which you are working. When the starter jaw is extended, its travel should be sufficient to assure full face engagement of the two sets of teeth.

13-49. *Starter test stand.* An aircraft starter test stand is used to test the performance and clutch setting (holding torque) of all models of aircraft reciprocating engine starters. The test

TABLE 2

JH STARTER CHARACTERISTICS

Coding Position	*Symbol(s)*	*Meaning*
1	JH	This symbol is used to designate those starters built by Jack and Heintz.
2	3 4 5 6 10	The numerals used in this position represent the manufacturer's basic model.
3	L	An "L" shaped starter with the motor located at a 90° angle to the starter jaw.
	N	Designed for use as electric direct-cranking.
	P	Starter has a special gear ratio.
4	E	Starters with this designation are equipped with a 7-inch diameter mounting flange.
	F	Signifies that the starter has a 6-inch diameter mounting flange.
		Note: No letter in this position also signifies a 6-inch diameter flange.
5	A	Starter has an axial type flexible shaft drive gear unit.
		Note: No letter in this position indicates that the 90° drive unit is used.
6	L	Starter jaw rotation is to the left or counterclockwise as viewed from the motor end.
	R	Starter jaw rotation is to the right or clockwise.

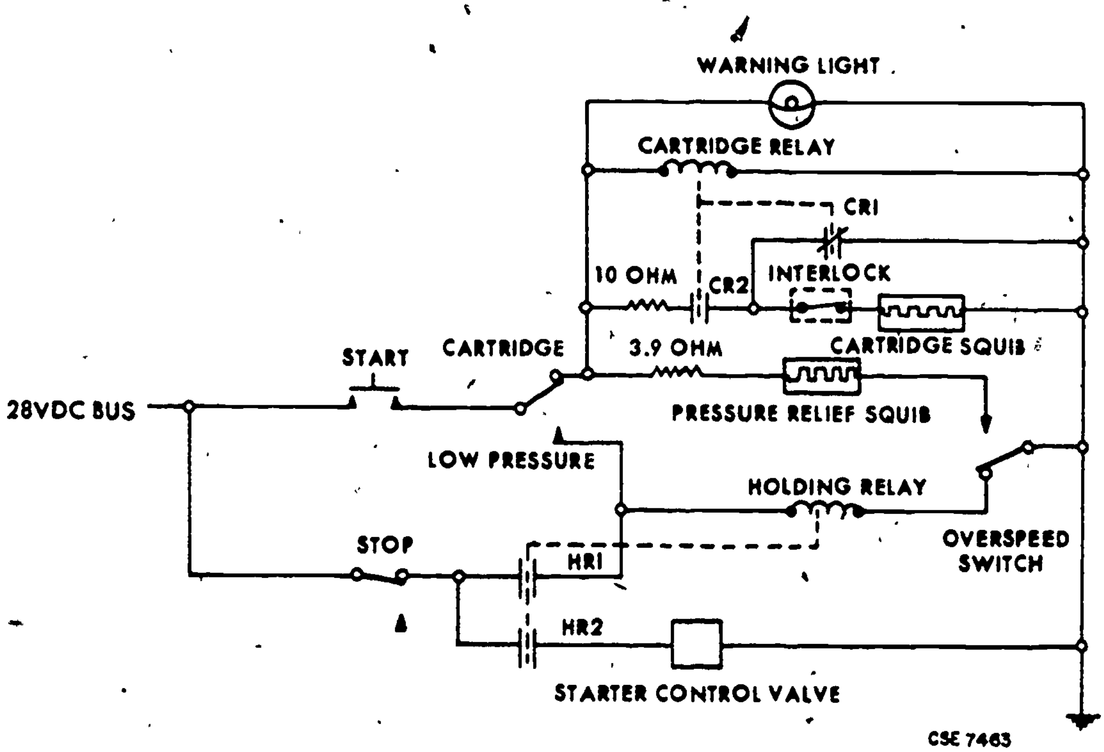


Figure 33. Cartridge pneumatic starter electrical system.

stand, more commonly referred to as the Prony brake, is fully equipped to test starters according to the manufacturer's specifications. In addition, it can be used to test various types of electrical actuators and retraction motors. The Prony brake is mounted on a heavy base or frame, and the cranking speed of starter jaws and the holding torque can be quickly and accurately determined from the various indicating meters supplied with the test stand, as shown in figure 34.

13-50. The tachometer, shown in figure 34, is used to indicate the rotational speed of the starter jaw in either a clockwise or a counterclockwise direction. The tachometer has two scales: a 0- to 150-rpm full scale and a 0- to 1500-rpm full scale. For convenience, the tachometer may be connected on either side of the test stand by simply interchanging the flexible drive shaft used with the unit.

13-51. The voltmeter and ammeter, also shown in figure 34, are used with the Prony brake to measure the direct current draw of the unit being tested at various values of dc input voltage.

13-52. For convenience of operation and in order to perform all the tests the test stand is designed for, three torque meters are provided. The torque meter assemblies are similar in operation and vary only in their operating range: One has a range of from 0 to 150 foot-pounds in increments of 2 foot-pounds; the second has a range of from 0 to 500 foot-pounds in increments of 10 foot-pounds; and the third torquemeter has a range from 0 to 1500 foot-pounds in increments of 20 foot-pounds. Since each torquemeter operates on compression, one is placed on the right arm of the Prony brake to test for right-hand rotation, while another torque meter is placed on the left arm to test for left-hand roation, as shown in figure 34. To make it easier to change torquemeters, the meters

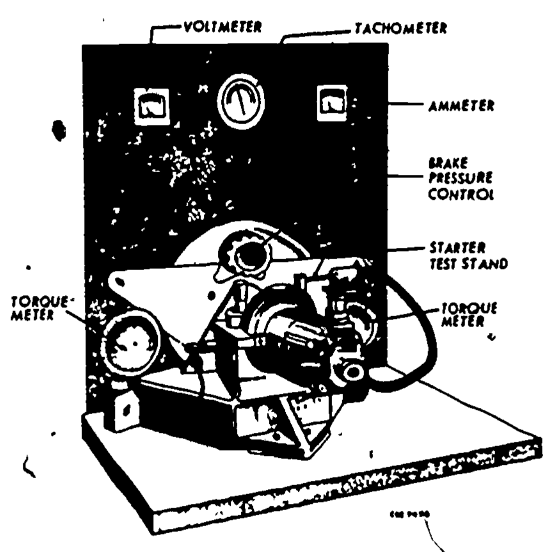


Figure 34. Starter test stand.

are anchored by two pivot pins at the end of the arm and in the base.

13-53. The brake pressure control (also shown in fig. 34) is used to adjust the brake load on the component being tested. The brake assembly is an aircraft type hydraulic brake that absorbs the load. Turning the brake pressure control clockwise applies pressure to the brake.

13-54. The starter test set is also furnished with a mounting adapter that can be used to accommodate all Air Force reciprocating engine starters. In addition, a complete set of starting jaws for testing starters and a set of couplings for use in testing actuators are furnished.

13-55. *Operation.* When the Prony brake is used to test a starter, always make sure that the starter jaw is fully retracted and clear of the test stand jaw. Also, make sure the torque meter is installed in the right arm for right-hand rotation starters and in the left arm for left-hand rotation starters.

13-56. When testing actuators, you must be careful to use the low reading torque meters supplied with the test unit. Under most conditions you will have to use two torque meters so that you can check the actuator torque in either direction.

13-57. As part of the testing procedure for some starters and actuators, you will have to operate the unit under no-load conditions. To accomplish no-load testing, it is necessary to release the brake pressure by turning the brake pressure control counterclockwise. When testing an actuator for no-load operation, it is advisable to lower the input voltage to prevent damaging the tachometer. This concludes the discussion of the Prony brake. When testing any component, be sure to refer to the appropriate technical reference for that component.

14. Auxiliary Components

14-1. At the start of World War II, aircraft used two magnetos and a starting aid (such as an induction vibrator) which were connected to the right magneto. During the war a triple unit starting coil was designed to take care of newer and larger aircraft which had three magnetos on one engine.

14-2. The triple unit starting coil, shown in figure 35, contains three identical circuits; in the schematic, however, only a single coil assembly is shown. The aircraft 24-volt storage battery supplies power for the unit. Its principle of operation is quite different from that of the induction vibrator, and any vibrating action will destroy it in a short time.

14-3. The starting coil should be mounted as close as possible to the magneto and starter so that you will have shorter leads, which increase the effectiveness of the unit because there is less loss of power.

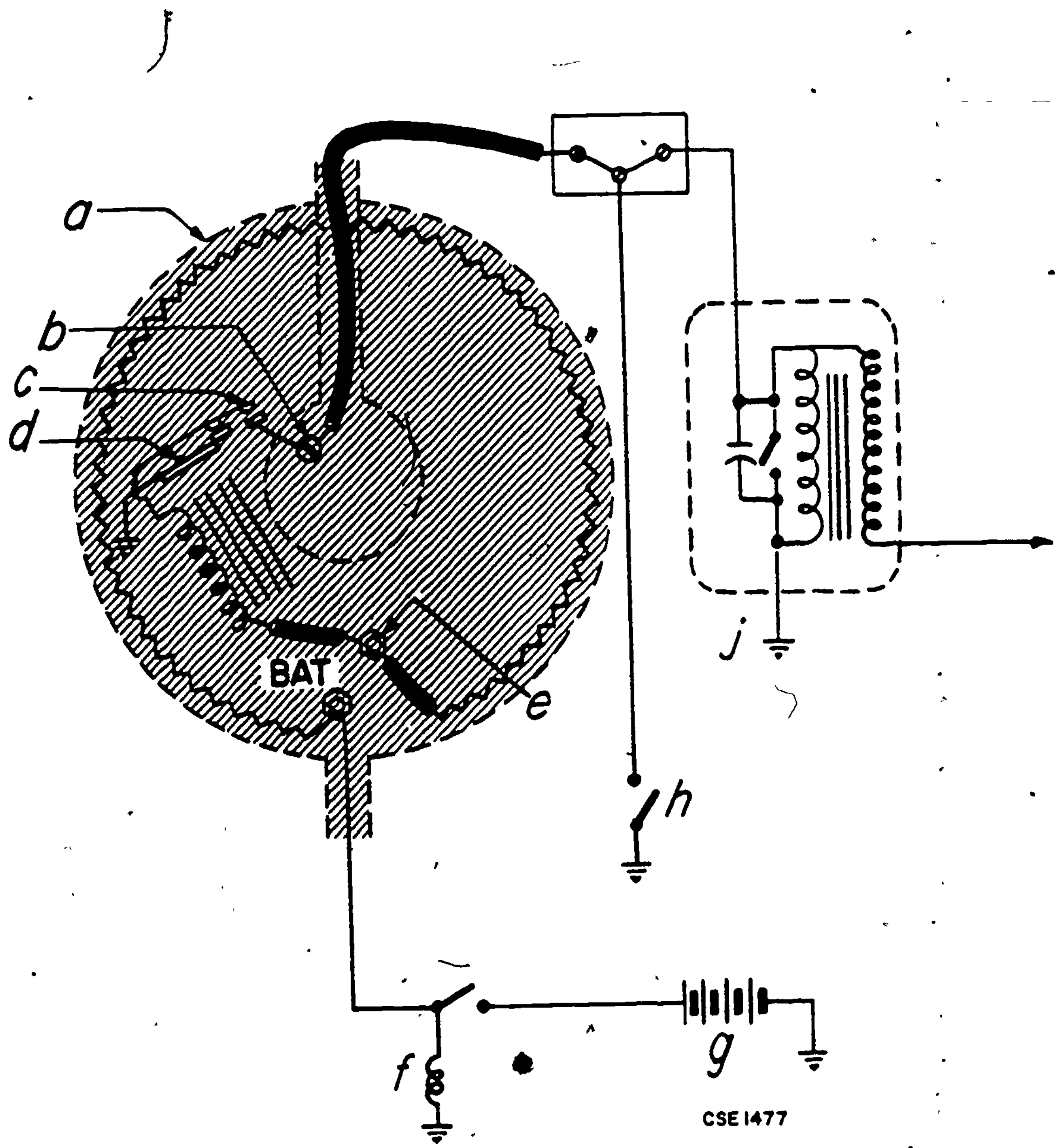
14-4. **Operation.** For this discussion, refer to figure 35. To energize the coil, the meshing switch (f) is closed. Power is then supplied from the battery (g) to the BAT terminal, and the starter is engaged to the engine through a connection to the starting circuit; thus, power is applied to the unit only when it is needed. From that BAT terminal the circuit is completed to the COIL CONNECTOR terminal (e) through a resistor (a) nested around the case. This resistor keeps the current flow at a safe value so that the primary coil in the magneto will not be damaged.

14-5. When the coil is energized, the magnetic field set up around it attracts the armature (d) and pulls it down. This allows the spring-actuated contacts (c) connected to the magneto terminal (b) to close and complete another ground circuit through the magneto breaker points and primary coil assembly. Also, as the armature moves down, the original ground for the coil is broken. But the coil remains energized, for it is now grounded through the magneto primary (j). When the ignition switch (h) is closed, the magneto primary is grounded out and the ignition does not occur.

14-6. The total resistance of the resistor around the case, the coil, and the primary coil of the magneto, connected in series, governs the current flow. If one of these units is bypassed, the amount of current will increase.

14-7. The unit which may be bypassed is the primary coil of the magneto. As the engine is turned by the starter, the magneto points connected as shown in figure 35 open and close. Each time the points close, a lower resistance path to the ground is completed because the points and the magneto primary coil are connected in parallel. The starting coil resists any change in current, and, as the points open again, the decreased current resulting from the increased resistance self-induces and sends a surge through the primary of the magneto. This power surge causes a buildup of the magnetic field in the primary coil, thus inducing a high voltage in the secondary. A current then flows through the distributor to the proper cylinder to fire the plug. With this type of starting aid, when the points open, only one spark is generated each time a cylinder is to be fired.

14-8. As the engine starts, the starter switch is opened, and the starting coil no longer has power. The spring tension on the armature points will open the points so that the circuit will break between the coil and the primary coil of the magneto. Again the circuit will be completed from the coil to ground, through the armature contact, and the circuit is ready for the next



a. Resistor
b. Magneto terminal
c. Spring-actuated contacts
d. Armature
e. Coil connector terminal
f. Meshing switch
g. Battery
h. Ignition switch
i. Magneto primary

Figure 35. Triple unit starting coil.

start. Now, let's discuss the switches that control these auxiliary devices.

14-9. **Ignition Switches.** Before starting an automobile engine, you must turn on the ignition switch. An aircraft engine is started in much the same manner. Let's see what the difference is, if any, between the ignition switch in an automobile and the ignition switch in an aircraft.

14-10. The automobile switch controls the electrical circuit to the ignition coil and, in most automobiles, also regulates the electrical power to such components as the heater and windshield wipers. The aircraft ignition switch also controls the ignition to the engine—but in a different way. Since a magneto furnishes the spark to fire the plug, it would do little good to disconnect the power from the battery. We need to make the magneto inoperative. If the magneto is driven, it can generate a voltage in the primary coil. If the primary coil is grounded out, however, only a small amount of voltage will be induced in the secondary coil—an amount well below the minimum required to fire a spark plug.

14-11. You should now be able to note the difference between the switches; the aircraft ignition switches closes the circuit when it is in the

OFF position, whereas that of the automobile, along with most other switches, opens the circuit when it is off.

14-12. *Single-engine ignition switches.* The ignition switch shown in figure 36 is typical of those used on single-engine aircraft which utilize a high-tension ignition system. The principle which is followed in constructing this switch is also used in the two-engine ignition switch. If you understand the operation of this switch, you will have very little difficulty in becoming familiar with the other types of ignition switches discussed later in this section. One lead (P-lead), connected with the aircraft ignition switch, is also connected with the primary control of the magneto. Another lead from the ignition switches goes to the aircraft structure and serves as the ground. All reciprocating engines have either single magnetos or dual magnetos. Each ignition switch will have the R (right), L (left), OFF, and BOTH positions.

14-13. When the lever is moved to L position, the right magneto is grounded and only the left one can operate. The reverse happens when the lever is moved to R position. Obviously, if OFF is indicated, both magnetos are inoperative. To start the engines, the ignition switch must be moved to the BOTH position. Naturally, the booster operates only during starting.

14-14. We have been discussing right and left positions, but we have not yet told you why we need to ground one magneto and to operate on the other. Each of the magnetos has a specific number of plugs to fire, and by being able to ground out one magneto, you can determine whether all the plugs are firing on the operating magneto. If there is too great a decrease in rpm, it is an indication that some of the plugs are not firing.

14-15. *Two-engine ignition switches.* The single-engine switch could be used on aircraft with two or more engines. However, such an arrangement would take up too much space on the instrument panel; therefore, to reduce the size of

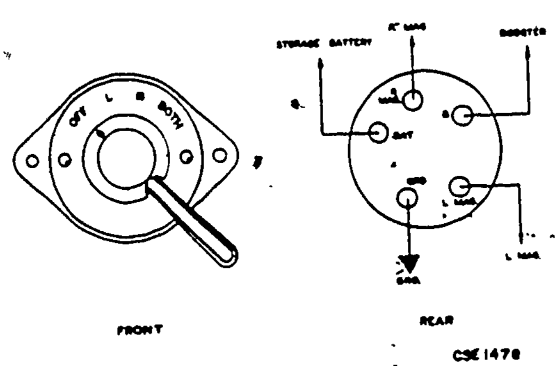


Figure 36. Single-engine ignition switch.

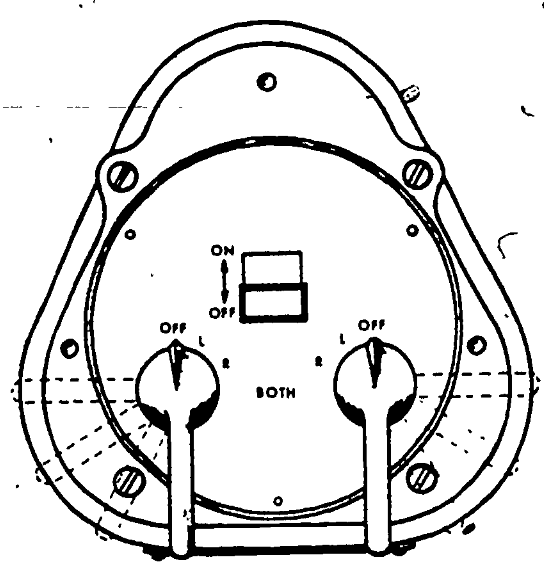


Figure 37. Two-engine ignition switch.

the panel, two single-engine switches are combined into one unit.

14-16. To compare the two-engine ignition switch with the single type, refer to figures 36 and 37. One item on the two-engine switch that is not found on the single-engine type is the ON-OFF button, located in the center of the face. This button, when pulled out, grounds out all magnetos. It is used in an emergency, such as a crash landing, to stop both engines. The individual sections work the same as those of a single-engine switch.

14-17. Another two-engine type has a toggle switch instead of the ON-OFF button. The positions are as designated in figure 37. The toggle switch serves the same purpose as the ON-OFF button. On aircraft that have four engines, there is a bar to fasten together the ON-OFF toggles of two ignition switches. This arrangement permits all ignition systems to be disabled at the same time by moving the bar to OFF during an emergency or when the engines have stopped on normal shutdown.

14-18. *Low-tension ignition switch.* The low-tension ignition switch which is used to control one engine is shown in figure 38. As you can see, its appearance is different from that of the ones previously discussed. Its rectangular shape allows the switches to be mounted closely together in one straight line. It is designed to control four magnetos per engine.

14-19. The construction makes it possible to connect the lever of all the ignition switches with one bar. Thus, with one lever the pilot moves them all. The lever grounds all magnetos when it is off. The low-tension ignition switch has only

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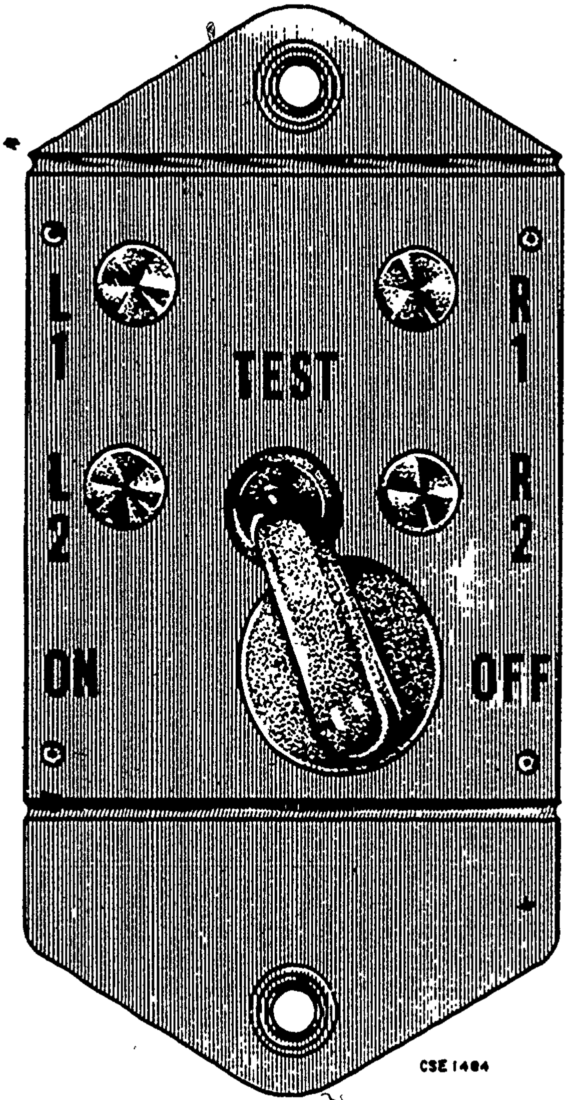

Figure 38. Low-tension ignition switch.

two positions, ON and OFF. When it is off, all magnetos are grounded. There are also four push-pull switches, one connected with each magneto. When the handle is pulled out, the switch grounds out the magneto that is marked beside the button. This is the reverse of the procedure for switches discussed earlier. In the latter types, if you want to check the right magneto, the switch is placed on R so that the left magneto will be inoperative.

15. Ignition Systems

15-1. Now that you are familiar with the various types of aircraft engine starters and their auxiliary components, we shall turn our attention to the various types of ignition systems you will work on as an aircraft electrician. Since you are primarily responsible for maintaining jet engine electrical systems, let us start with a typical ignition system known as the TEN-1.

15-2. **TEN-1 Ignition System.** The TEN-1 type is a turbo-electronic igniter system manufactured by the Scintilla Division of the Bendix Aviation Corporation. The "T" in the designation number stands for Turbo, the "E" for Electronic, the "N" for Scintilla, and the dash number for the particular model.

15-3. The TEN-1 ignition system consists of a dynamotor-filter assembly; an exciter; two high-tension transformer units; two high-tension leads; and two igniter plugs; together with the necessary interconnecting cables, leads, control switches, and associated equipment. There are only two igniter plugs, even though there are more than two combustion chambers in a jet engine. The reason for this is that the chambers are connected by crossover tubes so that the burning charge in one chamber will spread to adjacent ones and will ignite the charge in them.

15-4. The dynamotor is used to step up 28 volts dc, supplied by the aircraft battery, to the exciter operating voltage, which varies between 500 and 900 volts. This voltage charges two capacitors, which store the energy to be used for ignition. The discharge of the first capacitor, stepped up by a transformer, reaches the plug in the form of a high-frequency current. As a result, the voltage rise across the plug gap is extremely rapid, and the breakdown voltage of the gap is reached before any appreciable amount of energy can leak away through fouling or moisture, which may be present in the high-voltage circuit feeding the plug. On the other hand, the second capacitor discharge is of low frequency and low voltage, but of high energy. The result is a spark of such intensity that it is capable not only of igniting abnormal fuel mixtures but also of burning clear any foreign deposits which may be present upon the electrodes of the plug.

15-5. The exciter is a dual unit which produces a series of sparks at each of two plugs until the engine starts. The battery current is cut off when this occurs. These are the major points in the functioning of the dynamotor. However, the details vary, depending on whether the TEN system is regulated or nonregulated.

15-6. **Nonregulated and Regulated Systems.** A nonregulated system is one which causes firing of the igniter at an uneven frequency. This simply means that sparks will occur at the igniter whenever an ample charge builds up on the capacitor. The nonregulated system has a separate circuit, called a *sparking rate control*, which serves only to increase the rate of sparking during air starts.

15-7. The regulated system, as the name tells you, has an even rate of sparking; the electrical

power will be delivered to the igniter plugs at the same intervals of time, thus giving a more uniform burning process for starting. However, since this system does not have a separate circuit, the same sparking rate is used for starting in the air and on the ground. The regulated sparking is about midway between the high and low sparking rate of the nonregulated.

15-8. The nonregulated construction includes, as a part of the pilot control circuit, a test switch by means of which the operator may suppress the firing of either igniter plug in the engine burner. In this way, he can check each plug individually by cutting out the other one.

15-9. In the nonregulated system, a special dc dynamotor and radio interference filter comprise the assembly. Within the filter compartment is an operating relay which turns the battery input current off and on when the operator positions a remote switch.

15-10. *Nonregulated system dynamotor*. Now let us examine figure 39, which illustrates the non-regulated system. The dynamotor is a combined dc shunt-wound motor and dc generator. The low-voltage (28 volts) motor armature and the high-voltage (830 volts) generator armature are wound on the same shaft and, therefore, rotate in a common electromagnetic field supplied by the field windings in the housing. The output voltage depends on the speed of the armature. The field is of a constant strength and thus the output is stable. The commutator for the 28-volt winding is at one end of the shaft and that for the 830-volt winding is at the other. The field windings inclose the field pole pieces which are secured to the inner walls of the housing. The brushes fit into holders, which, in turn, go into sockets provided in the end frames. Bells inclose the open ends of the machine for protection against dirt, moisture, and mechanical damage. The connections, for input to the 28-volt motor, for output from the 830-volt generator, and a common ground, are brought out to terminals located in an extension at the top of the dynamotor housing. This extension mates with a hole in the bottom of the filter compartment, an arrangement that provides a convenient and protective passageway for the electrical conductors between the dynamotor and filter.

15-11. *Nonregulated system filter*. Also shown in figure 39 is the filter section. The purpose of the filter is to prevent radiofrequency disturb-

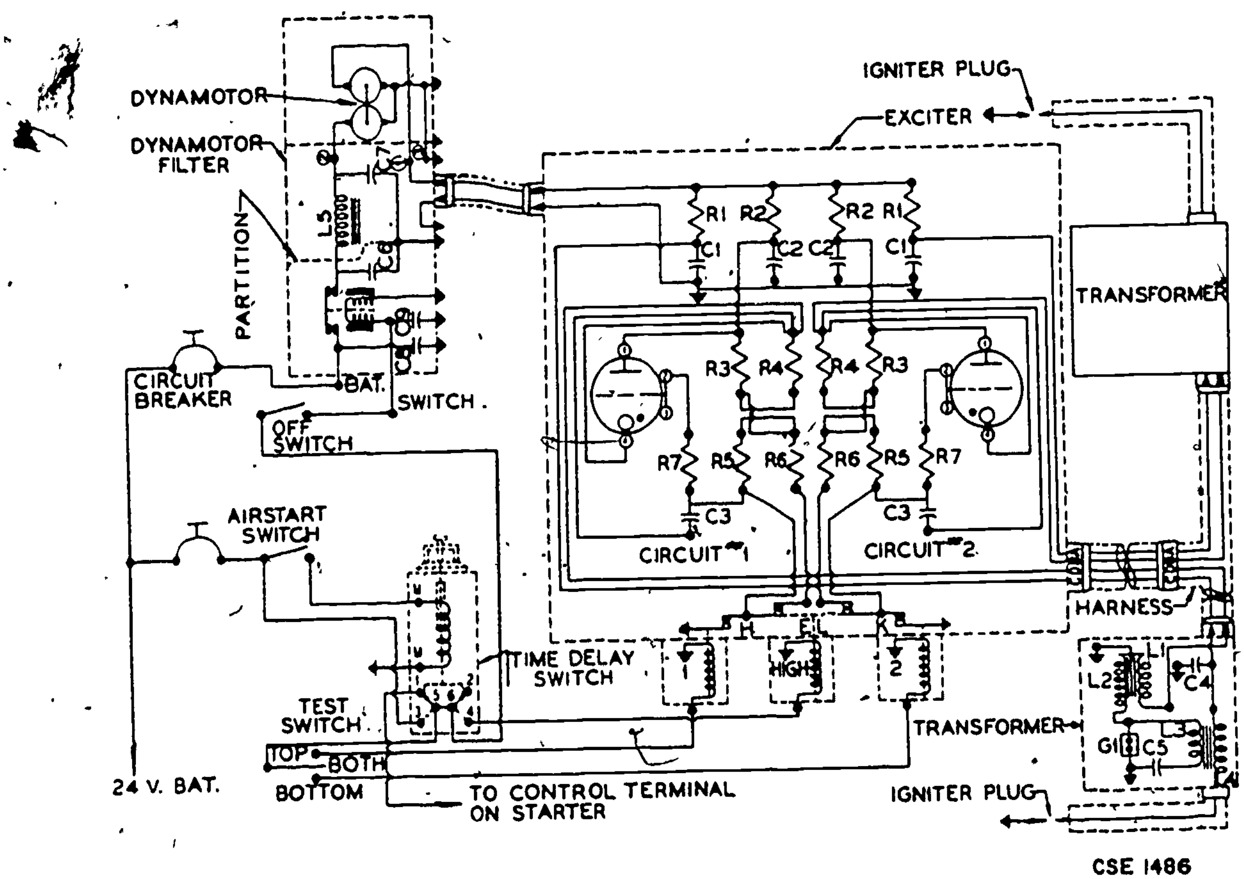

Figure 39. Nonregulated TEN system.

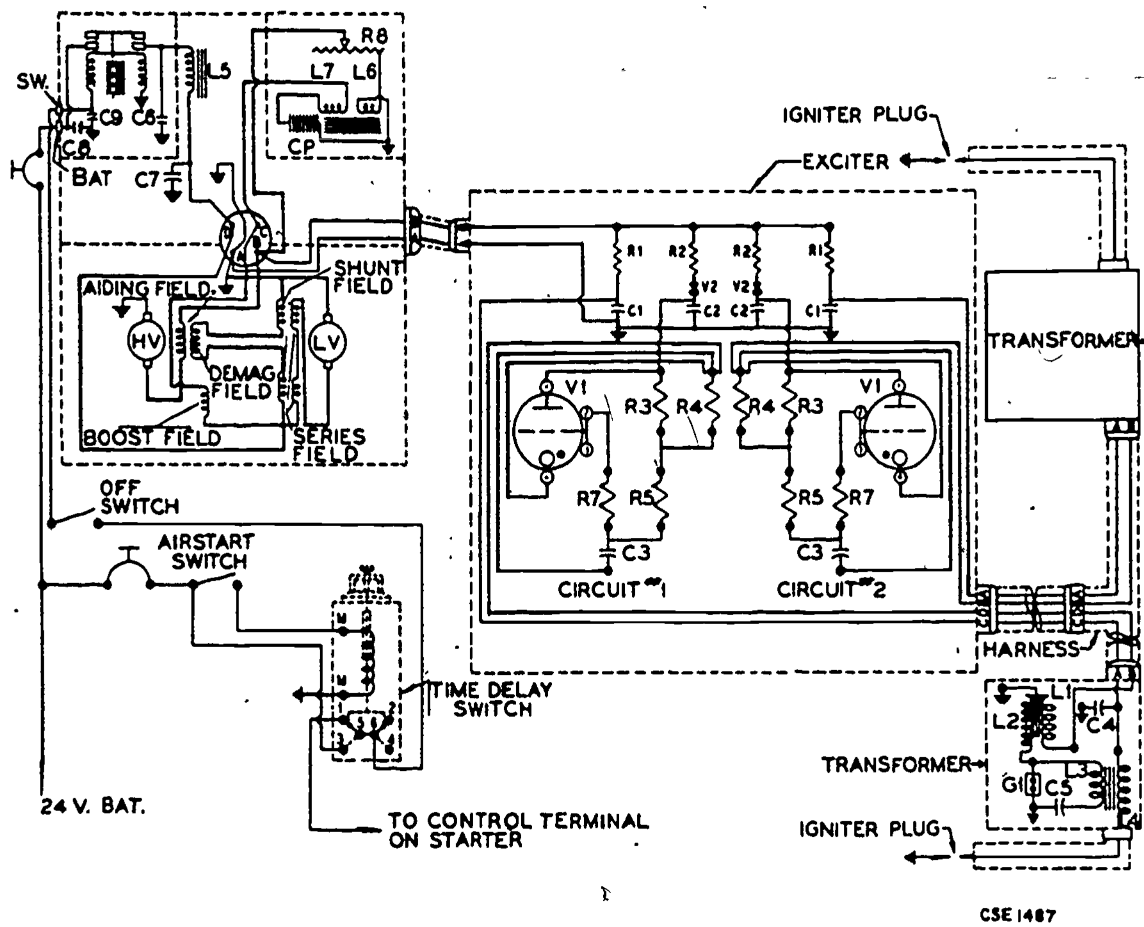

Figure 40. Regulated TEN system.

ances, which originate in the dynamotor or ignition system, from feeding back into the battery circuit. A choke coil is in series with the dynamotor input. This coil (L5) offers low resistance to the battery current, but offers high impedance to radiofrequency currents returning to the battery. At the same time, two capacitors (C6 and C7) provide a bypass to ground for the high-frequency currents. The entire relay is inclosed in a metal case to guard against the possibility of radio-frequency currents reaching the battery terminals through inductive or capacitve coupling. Two bypass capacitors (C8 and C9), located within the relay case and connected between the case, battery, and switch terminals, offer a further check against feedback. The relay is controlled by the OFF switch.

15-12. *Nonregulated system exciter.* Electrically, the exciter unit has two identical gaseous tube discharge circuits, designated as Nr. 1 and Nr. 2, each of which serves its respective transformer coil and igniter plug. The circuits are independent of each other, although the two large storage capacitors for Nr. 1 are contained within the same case as those for Nr. 2. The solenoid-actuated relays H, E, L, and K, which control the test-cutoff and air-start circuits, are also component parts of the base assembly. The letters stamped on the relay contact spring stops identify the relays, as shown in the electrical diagrams. The high-voltage direct current supplied by the dynamotor is fed into a two-contact electrical plug-in connector on the exciter base assembly through a shielded two-wire cable. The low- and high-frequency outputs of the exciter are delivered through a four-wire shielded cable, which connects through the engine harness to the transformer coils.

15-13. *Regulated system dynamotor filter assembly.* In the regulated system, shown in figure 40, the dynamotor-filter assembly also includes a carbon-pile voltage regulator. The filter, voltage regulator, and relay are found within a compartment at the top of the unit. The dynamotor is a two-pole, two-magnetic-stack machine. The stacks, two sections of laminated soft iron mounted on a common shaft, comprise the core, the motor, and the generator armatures of the dynamotor. The larger one is called the main stack, and the smaller the booster. The input

winding is wound only on the main stack. The high-voltage winding is wound in two sections: one over the main and booster stack and the other over the booster stack only. These two sections are connected in series on the high-voltage output commutator. Consequently, the voltage output is the sum of the voltages generated in the two windings.

15-14. The main stack gives straight dynamotor action, whereas the booster stack acts upon the output windings only and supplies generator action. Dynamotor action means simply that the output winding is wound over the input one and is energized by the motor field; therefore, the generator portion does not fall into one of the categories of ordinary generators mentioned earlier in this course. Generator action means that the field is energized by the output of the generator, of which it is a part. The unit is specially designed for use with a carbon-pile voltage regulator similar to those discussed in previous volumes.

15-15. The carbon-pile (CP in fig. 40) is connected with the booster field. As the input voltage increases, so does the current through the solenoid winding. This causes magnetization of the solenoid core, which then reduces the pressure on the carbon-pile and raises its resistance. The increase in resistance, in turn, lowers the current through the booster field. The decrease in current produces a reduction in the flux cut by the rotating armature, so the output voltage of the booster section of the HV winding is decreased. Thus, the combined action of the special windings in the dynamotor, the carbon pile, and the solenoid in the regulator tends to produce a constant output voltage, regardless of variations in battery voltage. The filter assembly (L5, C7, and C6), including the electrical portion, is the same as that for the nonregulated, except for the voltage regulator connections.

15-16. *Regulated system exciter*. The chief difference between the regulated and nonregulated exciters is that the regulated unit does not have the solenoid-controlled test cutoff and sparking rate relays. Another difference is the regulated system's use of selenium rectifiers.

15-17. *Transformer units*. Two transformer units, as shown in figure 40, are used on both systems, one for each igniter plug. Electrically, each unit is comprised of two transformers (L1 and L2, and L3 and L4), two capacitors (C4 and C5), and a spark gap (G1). These parts are inclosed in a single metal case. None can be diassembled or replaced except the spark gap. The spark gap is a separate, glass-inclosed part. The function of the transformer unit is to amplify the impulses delivered by the exciter, to convert them to high frequency, and to apply them to the igniter plugs. The energy from the exciter is fed into the transformer unit through a two-contact electrical plug-in connector. The output of the transformer is then conducted to the igniter plug through a short high-tension lead similar to the ones used on reciprocating engines.

15-18. *Time-delay switch*. The time-delay switch is used to introduce a predetermined time delay between the closing and the opening of the air-start circuit. Should ignition be required in flight, the pilot closes the air-start control switch. The air-start circuit then will operate for about 95 seconds, at the end of which time it will shut off automatically. The time-delay switch is an electropneumatic type; a solenoid closes the circuit, but its opening is delayed by a pneumatic mechanism which starts its timing cycle upon deenergization of the solenoid.

15-19. The time-delay switch consists of a timing head, a coil, a core and spindle, and a terminal block and switch. The principal components of the timing heads are an adjusting screw, a housing, a diaphragm, a valve, and a spring. The diaphragm is installed across a concavity in the pressed metal housing to form an air chamber, whose inlet is through a flat, seated valve in the diaphragm, and whose outlet is through an adjustable orifice in the housing.

15-20. The coil assembly has a box and a cover which inclose the coil. They are made of steel to form a part of magnetic circuit. The core and spindle include a magnetic core, operating springs, a spindle, and a collar. The upper end of the spindle is attached to the diaphragm coupling of the timing head. The spindle is permanently fixed to the magnetic core, and the collar at its lower end engages a switch secured to the molded terminal case. Switch springs are made of a beryllium copper alloy, and the contacts are made of silver. The remaining parts of the regulated and nonregulated systems are a dynamotor-exciter lead, exciter-engine disconnect leads, and the harness assemblies. High-tension leads carry the high-energy current to the igniter plugs.

15-21. **Operation of TEN–1 Systems.** As mentioned earlier in connection with the TEN–1 ignition system, the energy required to fire the igniter plug in the engine burner is stored in capacitors—not in an induction coil as in conventional systems.

15-22. Figure 41 shows a typical nonregulated system. There are two discharge tube and transformer circuits in the nonregulated system, but for simplicity of explanation only one circuit is pictured. During operation, the same action normally takes place in both circuits, which are energized by current from a single dynamotor.

15-23. It will be helpful to you to trace the sequence leading to the production of an ignition spark. When the engine starter is energized, current flows from the starter terminal on the engine to the Nr. 1 terminal on the time-delay switch (not shown) and then through its usually closed upper contacts to the off switch. This switch is closed for the engine starting so that current can flow to the switch terminal in the dynamotor filter and can pass through the energizing coil of the dynamotor relay. The closing of this relay connects the battery terminal, through the filter, to the dynamotor. Then the dynamotor begins its operation. As the dynamotor reaches full speed, it delivers a potential of from 500 to 800 volts dc through a shielded cable into the input terminals of the exciter unit.

15-24. Observe, in figure 41, that the dynamotor output is applied to capacitors C1 and C2 through resistors R1 and R2, respectively, causing the voltage of both capacitors to rise to the same value as that of the dynamotor. The voltage across C2 is also impressed across the discharge tube (T1) whose cathode is grounded through the low-resistance transformer windings (L1). At this time the voltage difference between the grid of the tube and the cathode is virtually zero; therefore, the tube is not in a conductive state. The voltage across the tube is also impressed across the series combination of resistors (R3 and R4). From their junction point, a connection is made through another resistor (R5) to the grid capacitor (C3), through a resistance of relative low value (R7), to the grid of the tube. As a result, a small charging current flows into the grid capacitor (C3) through R5, and the voltage on the grid slowly rises with the charge on C3 until its ignition (triggering) voltage is reached, at which time the tube is conductive.

15-25. Capacitor C2 now discharges through the tube, through L1 and the ground return path. As this occurs, the rise of current is extremely rapid and the resultant increase in flux induces a voltage several times greater in L2 than that in L1. L2 is the secondary winding; it has more turns than L1. This voltage is applied across the spark gap (G) and L3 and C5, which are in parallel with the gap. The voltage across the gap thus rises with the charge on C5 until the sparking voltage of the gap is reached, whereupon the gap becomes conductive. At this instant, its resistance drops rapidly, and the energy stored in C5 discharges across the gap. This initiates a high-frequency oscillation in the series-resonant circuit formed by C5 and L3. Transformer action between L3 and L4 greatly steps up the voltage across L4, from which point it is applied across the electrodes of the igniter plug (P). This high-frequency voltage causes a spark, even though the electrodes may be fouled with soot or oil, for the high rate of application ionizes and punctures the air layer between the electrodes of the plug (P) before there is time for any appreciable amount of energy to leak away. A capacitor (C4) provides a low-impedance ground return path for the high-frequency current induced in L4. As soon as this initial spark has made the plug gap (P) conductive, the resistance of the gap drops low enough to allow the large capacitor (C1) to discharge across it. The extremely high energy in this discharge provides a very hot spark that starts the charge burning and develops enough heat to burn away any foreign deposits which may be on the electrodes. The discharge of C1 and C2 lowers the plate and the

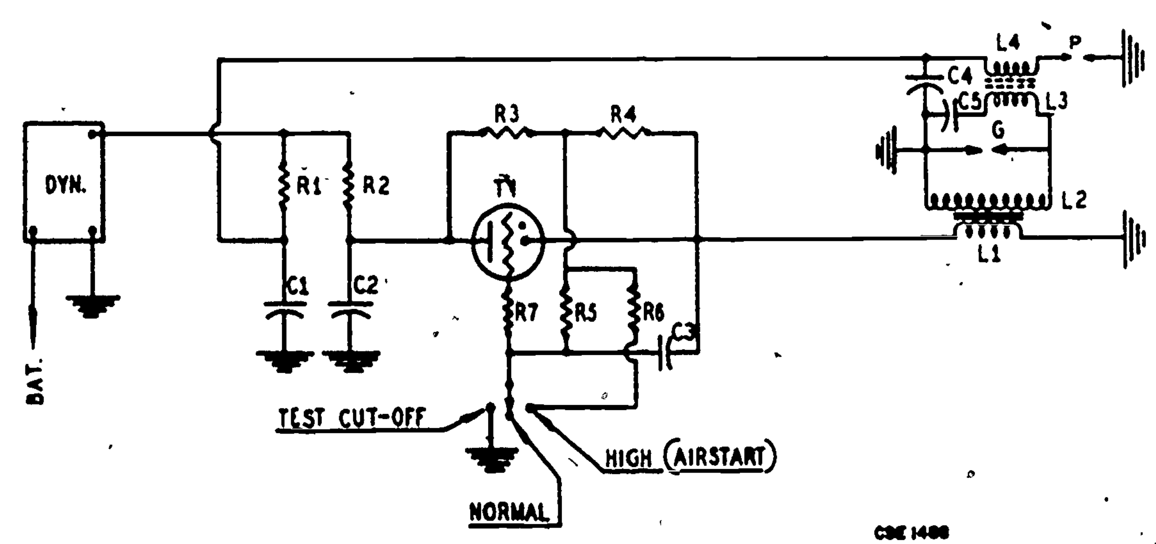

Figure 41. Single discharge circuit in nonregulated system.

grid potentials of the tube to a low value insufficient for further conduction. Thus, the tube is rendered nonconductive, and all action stops in the transformer and ignition plug circuits. The process is then repeated. In the low sparking rate position, the rate of operation is roughly 10 sparks per second.

15-26. When the switch is moved to the high sparking rate (air-start) position, R5 is shunted by R6. (See fig. 41.) Therefore, the time required to charge the grid capacitor to a voltage necessary to "trigger" the grid is greatly reduced. As a result, the rate of sparking is increased to about 30 sparks per second.

15-27. *Pilot-operated switches.* When the test switch is placed in TEST-CUTOFF, the grid capacitor is short-circuited and, consequently, the circuit is inoperative for purposes of test. In actual practice, the test and air-start switches are separate relay types, controlled remotely from the instrument panel.

15-28. The pilot-operated switches are not components of the electronic turboignition system, but are installed by the aircraft or engine manufacturers as adjuncts to control the operation of the system. For this reason, the design and wiring details of the control circuits may vary in different aircraft installations. The data which follows is offered for the purpose of general information as to the operating principles and not for purposes of service or detailed maintenance activity. The off (master) switch previously shown in figure 39 stops the entire ignition system when the switch is placed in the OFF position.

15-29. The air-start switch is, in effect, the control medium for the time-delay switch. When it is in the normal (OFF) position, the current for operation of the solenoid in the dynamotor relay is obtained from the starter terminal on the engine. The manner in which this circuit functions can be traced in the wiring diagram shown in figure 39. Current from the starter passes through the upper terminal of the time-delay switch, through the off switch contacts to the dynamotor relay, thus energizing it and closing the battery circuit to the dynamotor. In this position, the ignition system will function only during operation of the starter and at the low sparking rate used for ground starts.

15-30. When the air-start switch is closed, current flows through the solenoid of the time-delay switch and sets up a magnetic field which pulls the plunger of the solenoid down, throwing the contacts to the position indicated by the dotted lines in the diagram. Current now passes through the off switch to the dynamotor relay, energizing it in the usual manner, and then flows from the lower switch contact in the time-delay switch to the "high" solenoid in the exciter, energizing the relay and throwing the high sparking rate circuit into operation. Immediately upon the release of the air-start switch there is a 45-second time delay before the contacts resume their normal position. The high sparking rate circuit functions through this delay plus the interval during which the air-start switch contacts are held closed.

15-31. The time-delay switch functions as follows: when the control circuit is energized, solenoid action causes an instantaneous switch transfer, opening one set of contacts (solid lines in diagram) and closing another (dotted lines). The switch remains in this position as long as the air-start switch is closed. When the control circuit is deenergized, the time delay starts. At the end of 45 seconds, the contacts return to their original position. The adjusting screw at the top of the time-delay switch controls this interval. It should not be turned or disturbed; otherwise, the timing of the air-start circuit will be incorrect.

15-32. *Regulated system circuit.* The basic principle of operation of the regulated system is the same as that used in the nonregulated. The electrical circuits differ somewhat because of various improvements in the regulated system. The most obvious difference between the systems is the use of the regulated dynamotor, which we have already described. However, if you compare figures 41 and 42, you can see other major differences:

- R1, appearing in both systems, is a larger resistor in the regulated system to prevent damage to the dynamotor or exciter in the event of a short circuit in the harness or external circuits.
- The regulated system has a rectifier in series with R2. This rectifier, which feeds C2, improves the operating characteristics.
- The switch marked TEST CUTOFF, NORMAL. and HIGH (AIRSTART) in figure 41 is not included in the regulated system, since it does not use the solenoid controlled switches.
- R5 has different values in the two systems. This resistor controls the sparking rate of the system; its value provides a sparking rate for all conditions of operation, both on the ground and in the air.
- R6 does not appear in the regulated system.

13-33. The off-air-start, and time-delay switches, have the same functions as on the nonregulated system, but the connections between the time-delay switch and the exciter have been eliminated. In the regulated system, the sparking rate is the same as that used for ground starts, instead of being increased as is the case with the nonregulated.

15-34. A further comparison will clarify the function of the rectifiers. As already pointed out,

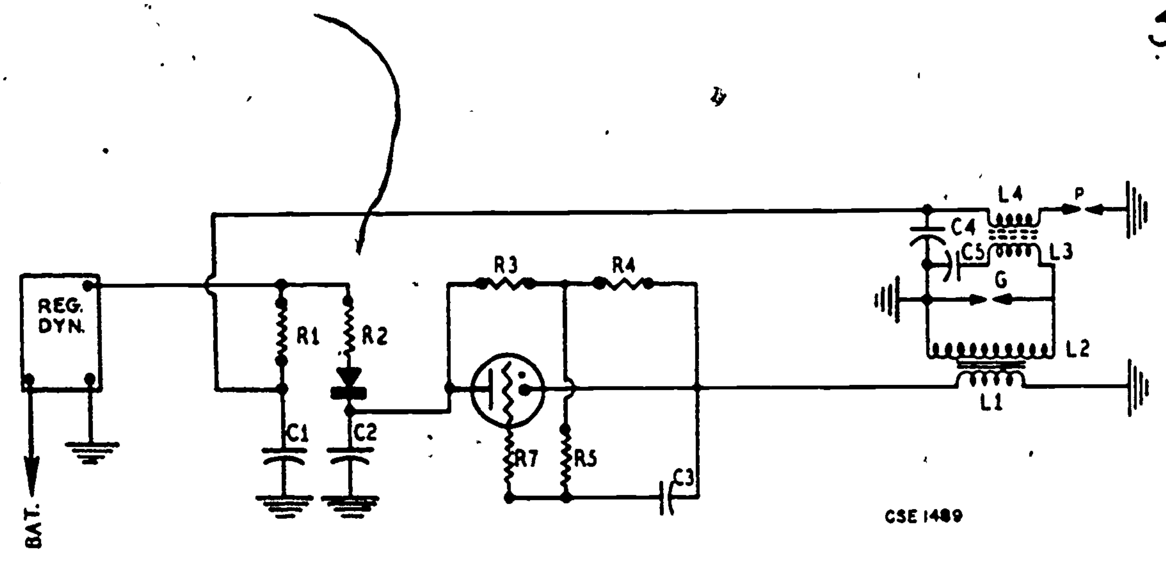

Figure 42. Single discharge circuit in regulated system.

there are two separate circuits in the exciter, and because of the slight electrical differences in the circuits, the sparking rate of one circuit may vary slightly with respect to that of the other. Of course, the same type of situation can occur in the regulated or nonregulated system.

15-35. Let us assume that both circuits are in operation and that Nr. 1 is firing a little faster than Nr. 2. At the start of a cycle, both C2 capacitors will be charged to the full value of the voltage delivered by the dynamotor. When Nr. 1 fires, the charge on its capacitor will be promptly dissipated through the external circuit of the system, and the voltage across it will instantly fall to a low value. Since Nr. 2 has not yet discharged, at this instant there is a fully charged capacitor connected through the R2's in both circuits to the discharge capacitor. During the interval immediately following the firing, a current will flow from the charged capacitor in the Nr. 2 to the discharged capacitor. This current lowers the voltage on the plate of the discharge tube in the Nr. 2 and may adversely affect its performance or even shorten its service life.

15-36. The rectifiers prevent the lowering of the voltage on either tube by the process just described. Since the rectifier restricts the current path to one direction, it does not allow any flow of current out of the capacitor in either circuit to go into the other branch through the two R2 resistors. The exciter-to-disconnect lead, harness, transformers, and igniter plugs used on regulated systems are electrically identical with those used on the nonregulated system.

15-37. This completes the discussion of TEN systems. These are found on older model aircraft, and all later ignition systems have been developed from the TEN. However, there are some major differences between later systems and the TEN. Let us see what they are.

15-38. **TFN-6 Ignition System.** The TFN-6 is a good example of a capacitor discharge ignition system. This system, illustrated in figure 43, furnishes a rapidly pulsating high-energy spark to ignite the fuel-air mixture in the combustion chamber.

15-39. Now we shall see how the TFN-6 system operates. Notice in the illustration that there are no moving parts in this ignition unit. Voltage from the 115-volt, 400-cycle power source is applied to the ignition unit through contact A, which is grounded to the housing. This allows current to flow through primary winding L2 of the power transformer, to choke coil L1 of the radio filter, and back through contact B to the source of power. By transformer action, L2 induces a voltage of higher potential across the secondary winding of L3.

15-40. When the upper end of L3 is positive, current flows from the negatively charged end of L3 to C3. This places a negative charge on the lower plate of C3. Current flows from the negatively charged end of C3 through V2 and V1 and then back to the upper end of L3. When the upper end of L3 is negative and the lower end positive, current flows through V3, V4, R1, ground, and to C4, charging the bottom plate of C4 negatively, and then back to L3. C3 and C4 are thus charged in steps on alternate half-cycles. Since C5 is connected in parallel with C3 and C4, it is also charged in steps.

15-41. When the voltage of C5 reaches a predetermined value, G1 will ionize. The ionization of G1 causes current to flow in the high-frequency oscillatory circuit of L4 and C7. This sudden surge through L4 causes a high-voltage high frequency across L5. This process ionizes the igniter plug gap. However, only a small amount of the total charge on C5 is required to ionize this gap. As a result of the ionized gap, a low-resistance path now exists across C5; and C5 discharges completely, expending most of its energy in the fuel-air mixture in the igniter plug.

15-42. R3, also shown in figure 43, is a load resistor which prevents damage to the ignition

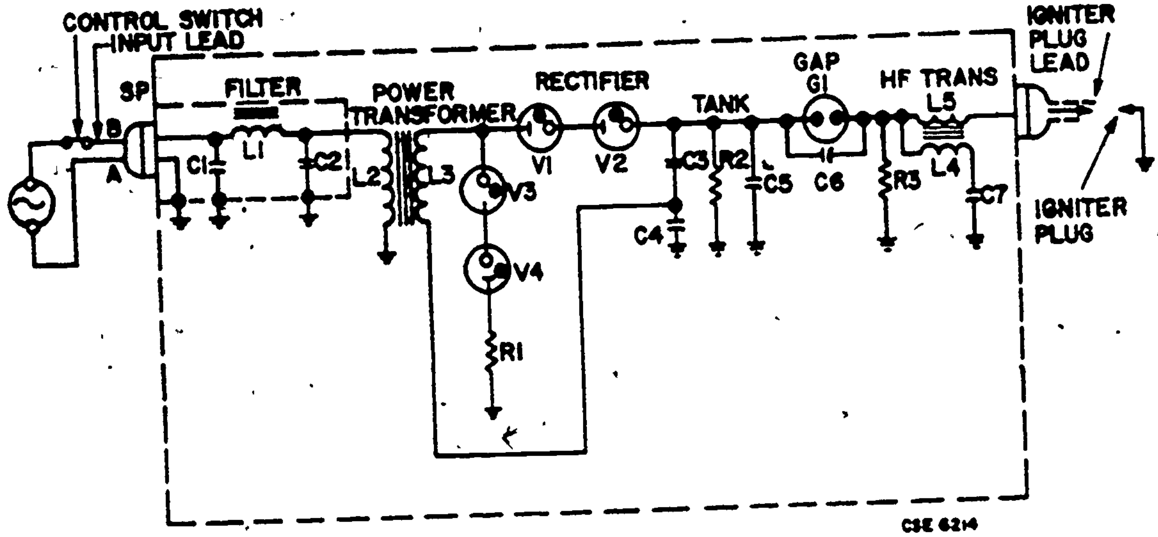

Figure 43. Capacitor discharge ignition system.

unit in case of an inadvertent open circuit operation; and it also discharges C7 between sparks. Notice C6, which is connected across G1. Its purpose is to help maintain a steady discharge voltage; it also prevents restrike of an arc through G1.

15-43. Thus far we have discussed how an engine is started and what ignites the fuel air mixture to keep it running. The electrician also has systems that control the engine once it is running so we will discuss some of them at this time.

16. Related Power Plant Control Systems

16-1. In this section we will discuss three systems that are used to maintain proper engine temperature. You as an electrician will be responsible for their electrical power. These systems are the cowl flap system, the oil cooler control system and the antidetonant injection system. We will discuss them in that order.

16-2. **Cowl Flap System.** All aircraft engines must have some means of maintaining operating temperatures. This is accomplished on reciprocating engines by controlling the air flow around the cylinders. This air flow is controlled by opening or closing the cowl flaps. What moves the cowl flaps? To find an answer to this question we will discuss a typical system. The first point of discussion will be the cowl flap actuator. Before we start our discussion, remember each aircraft will vary to some degree so consult the TO for your aircraft when performing maintenance on any of these systems.

16-3. *Actuator.* Each cowl flap actuator consist of a jackscrew driven by a split-field series motor. Some of these motors have a magnetic brake that prevents coasting when the switch is opened. The brake is released magnetically when the actuator is operated in either direction. In some cases, you may find that the motor drives two actuators through the use of flexible shafts and a gear reduction. By controlling the movement of the actuator the aircrew can maintain engine temperature at different altitudes and power settings. What is involved in controlling this actuator? If you will look at figure 44, we will find the answer.

16-4. *Open position.* To open the cowl flaps first we must put the control switch in the OPEN position. When we do this, there is a complete circuit from B1–48 through the control switch to ground at R2–17. This closes the open relay completing the circuit from B1–47 through the open relay, the limit switch, thermal switch, actuator to ground. At this time, the actuator opens the cowl flaps until the limit switch is mechanically actuated. These limits will vary so check the aircraft TO for the exact limits for a particular system. With the cowl flaps open, the air flow is at its maximum. What happens if the engine tempçraútre drops below normal? What do we do then? You are being inquisitive but if you keep it up you will be ahead of the game. Now let's warm that engine up again.

16-5. *Close position.* To increase the temperature of the engine we must slow down the flow of air around the cylinders. This is done by closing the cowl flaps. Again refer to figure 44 and place the control switch in the CLOSE position.

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With the switch in this position, a circuit is completed to ground from B1–48 through the control switch and R2–18, the close relay. When the close relay is energized, this completes a circuit from B1–47 through the close relay contacts, limit switch "A", the close coil of the actuator, the thermal switch, the actuator armature and to ground. When this condition exists, the actuator closes the flaps until the limit switch is mechanically opened. This will slow the flow of air around cylinders and allow the engine temperature to rise again.

16-6. All of this is fine, but it seems that the pilot either has a hot engine or a cold engine. Doesn't this switching back and forth take a lot of his time? Isn't there some way of reaching a happy medium in temperature? If so, just how does it work? To answer these questions, we need to go back to figure 44 again and clear up a few things.

16-7. *POS. position.* With the control switch in this position, control of the circuit is transferred to the potentiometer in the cockpit. This gives the aircrew complete control to stop the cowl flaps anywhere within their limits of travel. This control circuit consists of a micropositioner, a potentiometer in the cockpit and a follow up potentiometer in the cowl flap actuator. Check your switch position again so we are both together. It should be in the POS. position. Now let's see what happens.

16-8. With the circuit set as it is in figure 44, there is no current flow because the resistance of the "Pot" in the cockpit and the follow up "Pot" (the one in the actuator) is equal. What happens if the pot in the cockpit is turned up? When the resistance of the pot in the cockpit is changed, it creates a difference in potential between C1 and C2. This causes a current to flow in the micro-positioner coil which moves the armature to close contacts R or B, depending on the direction of current flow. Power at this time is applied to the actuator and it drives the cowl flap. As the actuator moves, the wiper arm of the follow up pot moves with it. When the resistance of the follow up pot is equal to the pot in the cockpit, there is no current flow in the micro-positioner coil and the circuit to the actuator is interrupted. In this position, the pilot can stop the cowl flaps any place he desires. Thus he can control engine temperature by controlling the air flow around its cylinders.

16-9. Some systems go one step farther than this. They work automatically. These systems have a heat sensor in the engine area that works in conjunction with the pot in the cockpit. When the temperature changes, it unbalances a bridge circuit which causes the actuator to reposition the cowl flaps to the desired setting. While we are discussing cooling systems, let's switch over to the oil cooler circuit while we are close by.

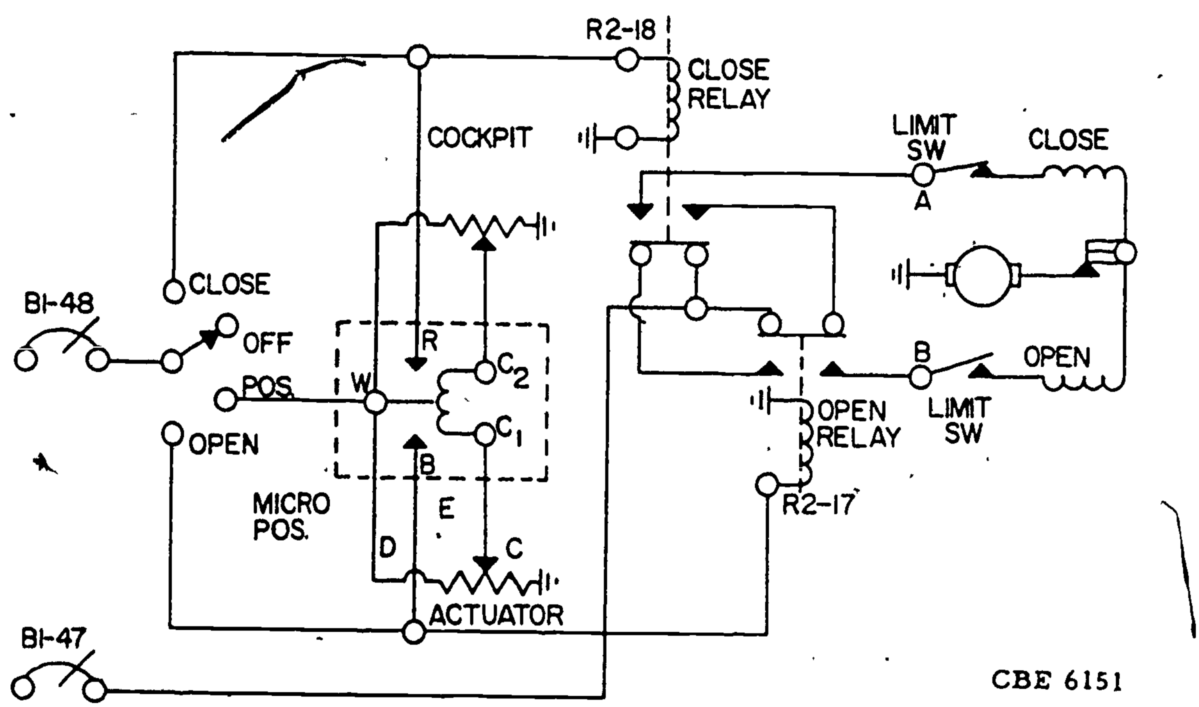

Figure 44. Cowl-flap control circuit.

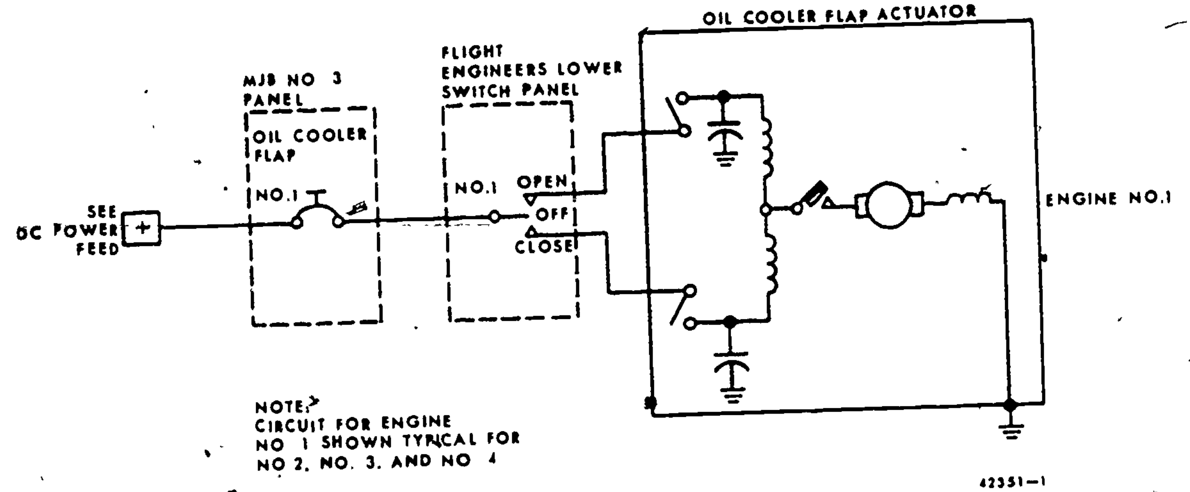

Figure 45. Oil cooler flap actuator circuit.

16-10. **Oil Cooler Control System.** This system is like the cowl flap system to the point that air flow is the cooling agent. By controlling the air flow through the cooler, the proper operating temperature of the oil is maintained.

16-11. *Oil cooler flap actuator*. The actuator changes electrical energy to liner mechanical movement. In doing this, it moves the oil cooler flap toward the open or closed position. Electrical power comes from the dc bus through a circuit breaker and is controlled by a three position switch. The positions are OPEN, CLOSE and OFF. The switch is spring-loaded to the OFF position. The liner movement of the actuator is limited by two adjustable limit switches. The motor of the actuator is radio noise free and has a magnetic friction brake. All of this is fine but how does it work? If you will take a look at figure 45, we will answer that question.

16-12. *Open circuit*. One thing we need to get clear before we hit the switch, is to become familiar with the way the circuit is drawn. Each manufacturer has a different way of drawing circuits. Basically they all look alike but there are always a few peculiarities. If you will note in this circuit, all the switches are open. So. when we mention normal operation you can assume that both the limit and thermal switches are closed.

16-13. Now that we have that little matter out of the way, let's place the control switch in the OPEN position and see what happens. This completes a circuit through the limit switch, the "open" field coils, the thermal switch, the brushes and armature, the magnetic brake coil, and to ground. When current starts to flow, the "brake" coil releases the brake and the actuator drives until the "open" limit switch is mechanically actuated. Remember though, the control switch is spring-loaded to the OFF position so any time the switch is released the circuit is interrupted. This will engage the magnetic brake and stop the actuator. Thus the aircrew has full control of the oil cooler flap.

16-14. *Close circuit*. This circuit is the same as the open circuit except the "close" coil of the actuator causes it to operate in the opposite direction. Look at figure 45 again and trace the "close" circuit out. You should know what happens. If you run into a problem go back and read the paragraph on the "open" circuit.

16-15. How about those condensers in the circuit? What are they for? If you remember, a few paragraphs back we said that the actuator motor was radio noise free. These condensers are the reason for this. Between the limit switches and armature action there is quite a bit of arcing in the circuit. The condensers prevent much of this arcing and filter out the radio noise.

16-16. This concludes the discussion on the oil cooler control system. There is one other area we need to discuss before we leave the power plant control systems and that is antidetonating injection system commonly referred to as the ADI. Don't let the name shake you up too much. It really isn't as bad as it sounds.

16-17. **Antidetonating Injection System (ADI).** Many people refer to this system as the water injection system, you will see why as we discuss it. There are times when the pilot wants every bit of power he can get out of an engine without exceeding its safe limits. At such times cylinder head temperatures soar to a maximum and detonation could occur. To prevent detonation a water-alcohol mixture is injected into the cylinder. The flow of ADI fluid is controlled by a water regulator and is also proportional to the rate of the fuel flow to the engine. Just what does the electrician do to maintain this system? Isn't this system in the engine mechanic's area of

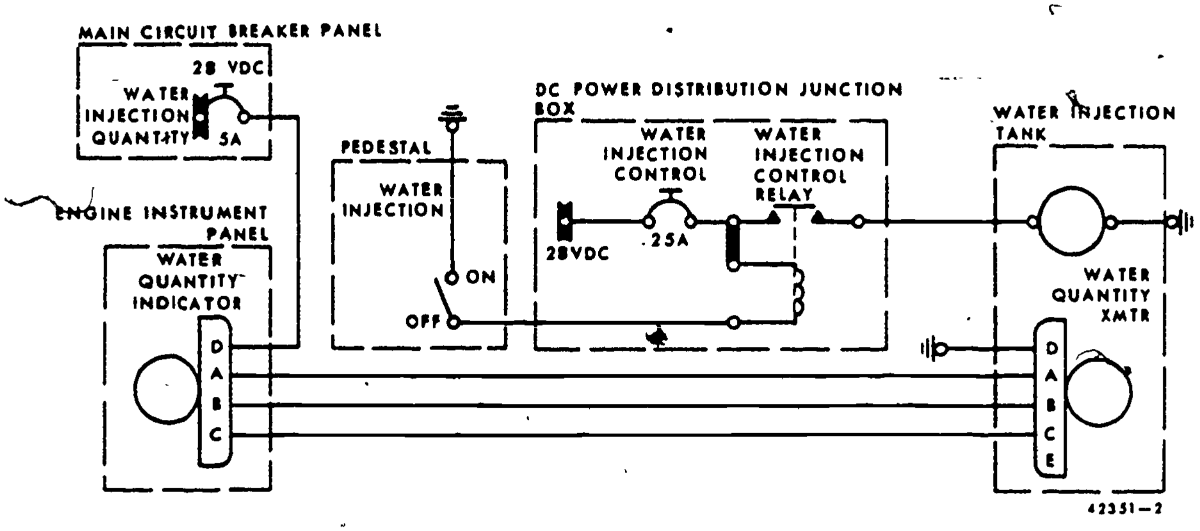

Figure 46. ADI control circuit.

responsibility? Well, yes, it is the mechanic's system but there is a small item, like an electrical driven pump, that we have to consider. Along with this, we have a power circuit and a control circuit to maintain. The major electrical component is the pump assembly so we will start our discussion there.

16-18. *Water injection pump.* A typical pump assembly is a 28-volt dc motor that drives a centrifugal pump. The motor and pump are sealed in a water-tight housing which is submerged in the ADI fluid. The pump is controlled by a switch in the cockpit. The control switch operates a relay that, when closed, delivers power to the pump motor. Take a look at figure 46 and you will see the electrical circuit for the system.

16-19. *Circuit operation.* First you will note there is a water quantity circuit in the drawing. We will bypass this portion of the system since it belongs to the instrument people. Our portion of the system is the control circuit and power circuit. You will note that power for both circuits is supplied by a 28-volt dc bus and they are also protected by the same 25 amp circuit breaker. When the control switch is placed in the ON position, a circuit is completed from the power source through the circuit breaker, the control relay coil, the switch and to ground. As current flows through the relay coil, the contacts are closed, and power is applied to the pump motor. The system continues in operation as long as the switch is in the ON position. The pilot only uses this system when he needs to use high power settings. This concludes our discussion on ways of controlling the power plant and related systems. We will now turn our attention to utility systems.

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Utility Systems

THERE WAS a time when people used lights that demanded much more attention than lights which we use now. Many years ago maintenance of lighting equipment such as kerosene lamps required filling the reservoir, cleaning the chimney, shaping and cleaning the wick, and adjusting the height to give the meager yellow flare of light that was used for all lighting purposes. Before the kerosene lamp was used dripping fuming candles were used for lighting. In any event, the housewife spent a good deal of time maintaining and servicing lighting equipment.

2. As the electric light became more and more common, the maintenance of lights and lighting equipment became less and less of a chore; today when a light fails we merely assume that the bulb has burned out. Ninety nine times out of a hundred, replacing the bulb restores the light to a serviceable condition. If it were not for the great dependability of present-day electrical equipment, the operation of highly complicated equipment such as automobiles and aircraft would be much more of a problem. Electrical equipment includes the lighting systems which are used on aircraft and which are the subject of this chapter.

3. Lights on an aircraft are used for two purposes. Some lights are designed to attract attention or to be seen. Others are designed to flood an area with light so that details in the area may be recognized. Lights for both purposes are used on aircraft and both types of light may be found in the group of systems designated as interior lighting systems. The same may be said for the lights designated as exterior lighting systems. We shall cover both interior and exterior lighting systems in this chapter and we shall also discuss some of the methods of circuit analysis and troubleshooting.

17. Interior Lighting Systems

17-1. The types and numbers of interior lighting systems vary from one type of aircraft to another. Small aircraft, such as fighters, have instrument lights, panel lights, white and red floodlights, and a portable spot and floodlight. Larger aircraft, such as bomber and cargo planes, have several other interior lighting systems. These include entrance and aisle lights, walkway and crawlway lights, bomb bay lights in bombers, or cargo bay lights for cargo-type aircraft. The necessary panel and instrument lights are installed at each crewmember's station.

17-2. **Instrument Lights.** Lights which are used to illuminate instruments may be divided into two groups, primary lights and secondary lights. The primary lights consist of individual lights located inside the hoods to provide illumination for one particular instrument. Included with primary lights are edge lights, which illuminate the lettering on the control and circuit breaker panels. These lights are mounted in the plastic panels so that the light radiates only through the plastic. The panels are painted with a black vinyl lacquer. Lettering on the panel is etched through the lacquer so that the light radiating through the plastic makes the lettering easy to read. The secondary lights are floodlights that provide light for the instruments when the primary system fails.

17-3. *Instrument lighting circuits.* A simplified schematic of a typical instrument lighting circuit is shown in figure 47. Notice that the system is powered by 115-volts ac. The high voltage is reduced by a variable transformer which maintenance personnel refer to as a "Variac." The CONSOLE LIGHTS CONTROL permits a variable voltage from zero to 28 volts. From the wiper arm of the variable transformer you will notice the power is applied to the EDGE LIGHTS, the STANDBY COMPASS light, several panels shown at the bottom of the schematic, and to an autotransformer that supplies the integral instrument lights. This voltage varies from zero to 5 volts as the wiper of the CONSOLE LIGHTS CONTROL is moved from OFF to BRT.

17-4. *Floodlights.* If the instrument light circuit fails, the pilot still has the left and right console floodlights and the instrument panel emergency floodlights. The circuit for these lights is

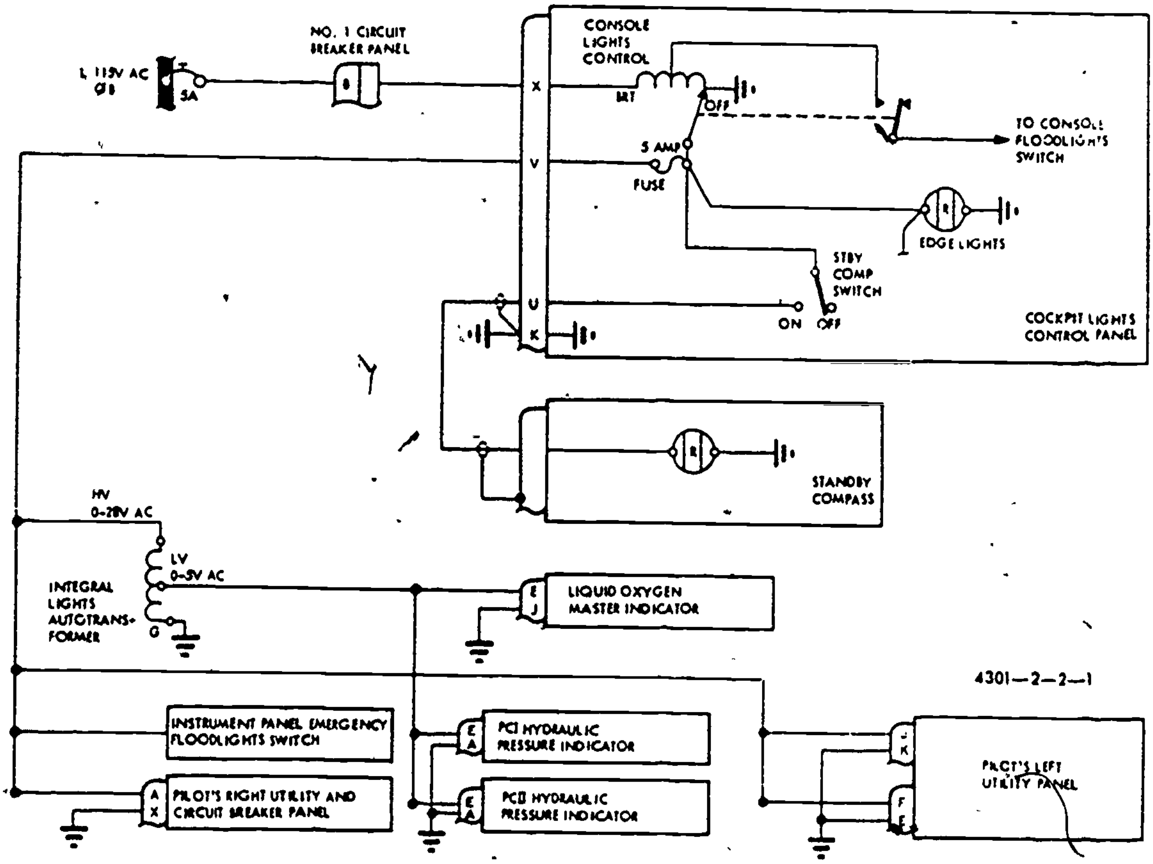

Figure 47. Panel lights.

shown in figure 48. This figure illustrates a typical circuit, but it may be quite different from circuits with which you are familiar. The SPDT (single-pole, double-throw) SWITCH, which is mechanically connected to the wiper arm of the CONSOLE LIGHTS CONTROL variable transformer, is actuated whenever the CONSOLE LIGHTS CONTROL is moved from the OFF position. Therefore, the LEFT and RIGHT CONSOLE RED FLOODLIGHTS are on whenever the instrument lights are on. The pilot can switch them from dim to medium or bright. When they are switched to the DIM position they have 7.5 volts applied. When they are switched to MED they are connected to a 14-volt bus, and when they are in the BRT position they have 28 volts applied. The floodlights have red lenses to reduce night blindness.

17-5. White floodlights are provided on most aircraft for use during thunderstorms to lessen the blinding effect of lightning flashes. They are also used in the daytime during dull light connections. These lights are often connected to the dc bus and serve as emergency instrument lighting if ac power fails.

17-6. A utility spotlight, commonly referred to as a "C–4" light, is generally located at each crewmember's station on most aircraft. It is attached to a long, coiled, electric cord. It can be removed from its mounting bracket and attached to any convenient spot by means of a spring clip. The light can be changed from red to white by turning the lens housing. The light contains an integral ON-OFF SWITCH that includes an intensity control. A pushbutton is provided on the case near the control switch. This button provides full light intensity, regardless of the setting of the intensity control. This light may be used for utility purposes as well as for mapreading.

17-7. **Warning Lights.** The number of warning lights installed in an aircraft varies, depending on the number and complexity of its systems. Each warning light is studied as a part of its specific system. However, provision is usually made for testing the operation of the lights as a group. In most cases this is done by means of a momentary contract toggle switch. When the switch is held on, the warning lights will illuminate, and they will go off when the switch is released. Warning lights are used to indicate unsafe conditions, such as landing gear that is not locked, low fuel level or pressure, or possibly a bomb bay door that is not completely closed.

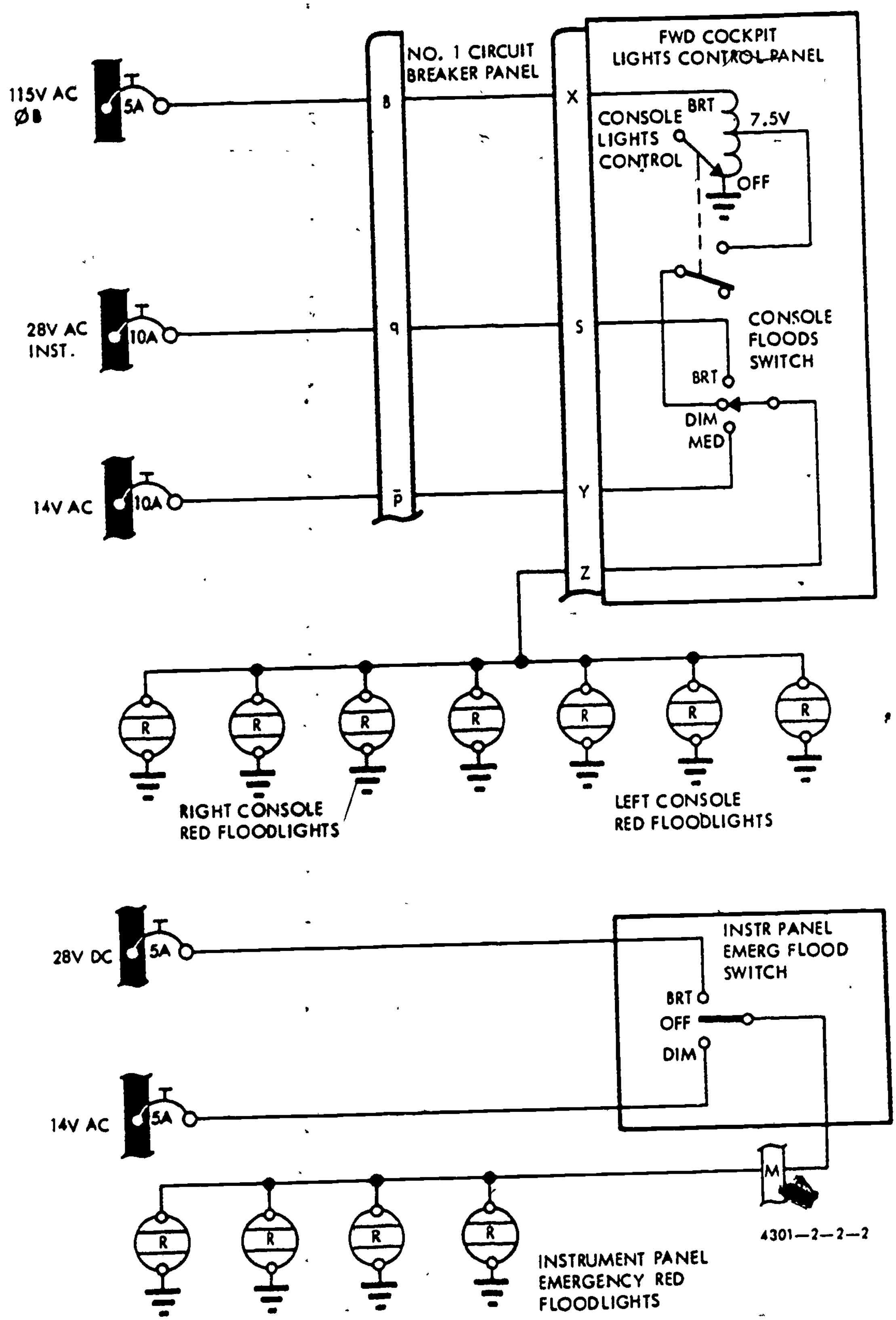

Figure 48. Floodlights.

17-8. **Other Interior Lights.** So far in this chapter we have discussed the lighting systems found on most aircraft. The larger tanker, cargo, and bomber-type aircraft have several lighting systems that are not required on the smaller craft. Cargo and passenger aircraft have cabin and cargo compartment lights, which, of course, are unnecessary on other aircraft. Bombers have bomb bay lights and crawlway and walkway lights, as well as lights in equipment storage areas.

17-9. Tanker aircraft such as the KC-135 have lights in the boom operator's compartment that are similar to the lights in the pilot's compartment. These include instrument and panel lights, floodlights, and a utility spotlight; all of these have been described earlier.

17-10. Wheel wells on the larger aircraft also contain lights to provide illumination, either in flight or on the ground, for the wheel well and surrounding areas. A control switch is generally found in one wheel well which the refueling crew can use to provide light for single point ground refueling. The wheel well lights may be operated on either ac or dc power. This situation enables the ground crew to operate the wheel well lights on dc power during ground refueling operations.

17-11. The trend in modern aircraft is toward ac lighting systems. Provisions are incorporated in these aircraft to provide dc power for emergency lights. Cabin lights, cargo compartment lights, and the ground refueling light are some of the lights which operate from this dc power.

18. Exterior Lighting Systems

18-1. The exterior lighting systems generally fall into one of two categories: those which increase pilot visibility or those which attract the attention of other aircraft. The first category of improving visibility pertains to the landing and taxi light systems. These systems provide the lighting that is required on takeoffs, landings, and ground taxi operations. The second category of exterior lights, that of attracting attention, helps to prevent aircraft collisions. Systems that are designed to attract attention include navigation lights (often called position lights), ANTICOLLISION LIGHTS, and join-up or formation lights. On aircraft that can be refueled in flight, lights are installed in the air refueling receptacle and at the wing roots for overwing lighting. Tanker-type aircraft also have additional exterior lights to facilitate refueling.

18-2. **Landing Lights.** The landing light or lights are mounted so that when they are turned on they direct a beam of light forward. As their name implies, these lights are used for illumination during night landings. Landing light systems vary from one aircraft to another, but a typical circuit for an entire exterior lighting system is shown in foldout 6. The control voltage for the landing light comes from the dc bus through a 5-ampere circuit breaker and the LANDING LT AND TAXI LIGHT SWITCH to the LANDING LIGHT RELAY. The relay ground is through the left main landing gear down limit switch. This insures that the landing light will not come on with the landing gear up. When the relay closes, 28 volts of ac power is applied to the landing light filament. In this particular installation, the landing light is installed in the door that covers the nose wheel well. When the wheel well door is open, the landing light is in proper position for landing.

18-3. As we mentioned earlier, landing light systems vary between aircraft. On some aircraft, a landing light is mounted in the leading edge of each wing, a light is attached to the nosewheel, and a retractable light is on the underside of the right wing. The two wing lights can be turned on and the retractable light can be extended and turned on with the landing gear up. The nose gear light will not come on until the gear is down and locked. Dc is used to control the landing lights, including the motor of the retractable light; however, the filaments of all of them are energized by 28 volt ac. The retractable light is extended and retracted by a dc reversible motor. Limit switches are incorporated into the circuit to limit travel of the lamp assembly and turn off the light when the assembly is retracted.

18-4. Another landing light system includes a crosswind landing light and a terrain clearance light. The crosswind landing light is mounted on the steerable front wheels and illuminates the area in the direction in which the front wheels are aimed rather than in the direction in which the aircraft is aimed. During the crosswind landing, the two directions may be quite different. The terrain clearance light is a retractable light that directs its light (when extended) down and forward so that the pilot may better judge his distance above the runway.

18-5. One more landing light system is a retractable type of assembly. The assembly carries a lamp which has two filaments of different wattage ratings. The high-wattage filament is in use when the control switch is in the LANDING LIGHT position, and the low-wattage filament has power applied when the switch is moved through OFF to the TAXI position.

18-6. **Taxi Lights.** Taxi lights are used on aircraft to provide light while the aircraft is being taxied at night. They are often less bright than the landing lights, as indicated in the above paragraph, but they are usually mounted in almost the same position. The taxi light system shown in the exterior light schematic (FO 6)

uses a separate terminal of the same control switch as the landing light and parallels the landing light circuit throughout.

18-7. On systems that employ the crosswind landing light, a crosswind taxi light is also mounted on the same bracket. This provides light ahead of the wheels when they are not pointing in the same direction as the aircraft because of a high crosswind.

18-8. In a typical tanker aircraft system, the wing illumination lights are incorporated into the taxi light system. The taxi and wing illumination lights may be turned on in flight to provide light during air refueling operations.

18-9. **Position Lights.** The position lights are often called navigation lights. These lights are mounted on the wingtips and tail assembly of the aircraft. The left wing light is red, the right wing light is green, and the taillight is white. On the schematic of exterior lighting systems (FO 6), it can be seen that the position lights are closely associated with the join-up lights. The join-up lights take the place of formation lights on some other types of aircraft. On the external lights control panel are two switches that control the position lights. One of them controls both wing lights and the other controls the taillight. The lights may be turned on either bright or dim.

18-10. Power for the lights when they are on BRT comes from a 28-volt ac bus through a 15-ampere circuit breaker. Power for the DIM lights comes from 14-volt ac bus through a 10-ampere circuit breaker. Power for the wing lights then goes from the switch directly to the light transformers, where the voltage is stepped down to 6 volts for both the position lights and the join-up lights. Power for the white taillight goes to a set of contacts in the FLASHER RELAY and then to the taillight transformer. Notice the flags numbered "6" at the transformer and at the light. These flags indicate a note at the bottom of foldout 6 which tells us of a change in wiring on some installations.

18-11. In order for the taillight to come on, the set of contacts in its power lead controlled by the flasher relay must be closed. In this way the white formation light is tied in with the flasher system and the anticollision system. Power to close to the FLASHER RELAY comes through the ANTICOLLISION SWITCH. When the switch is in the STEADY position, the FLASHER RELAY stays closed. When the switch is in the FLASH position, power to the FLASHER RELAY is interrupted by the flasher as it opens and closes the circuit. In the STEADY position, 28-volt dc is applied across the switch, across the jumper between B and C terminals of the flasher, and on the coil of the FLASHER RELAY. The taillight will now illuminate and remain as a steady white light.

18-12. When the ANTICOLLISION SWITCH is in the FLASH position, the dc power is applied to the A terminal of the flasher, causing the flasher to operate. The flasher consists of a dc-motor that drives a rotary cam which opens and closes a set of contacts that energize terminals B and C at intervals. The interrupted power is then applied to the FLASHER RELAY, which opens and closes, causing the taillight to flash on and off. The flasher also controls the ANTICOLLISION LIGHTS.

18-13. **Anticollision Lights.** The ANTICOLLISION LIGHTS are designed to flash on and off to attract the attention of other nearby aircraft so that collisions may be prevented. In our schematic circuit, the ANTICOLLISION LIGHTS and FUSELAGE LIGHTS are interconnected. Power for one (upper one on FO 6) of the ANTICOLLISION LIGHTS comes through a 10-ampere circuit breaker from the 28-volt ac bus. It passes through a set of contacts of the FLASHER RELAY and the ANTICOLLISION RELAY before going to the light. Therefore, both relays must be energized before this light will illuminate.

18-14. Power for the other ANTICOLLISION LIGHT comes from the 28-volt ac line through a 15-ampere circuit breaker. This circuit breaker is larger than the circuit breaker which serves the other anticollision light, because power for the fuselage lights also comes through it. Power for this ANTICOLLISION LIGHT also passes through contacts in both relays and then on to the lights. At the FLASHER RELAY, a lead joins the anticollision power lead. This lead connects to a set of flasher relay contacts, which when closed will permit power to go to the fuselage light switch. From the switch it goes to the fuselage lights in either the DIM or BRT position. When it is in the BRT position, the flasher will be energized by the jumper across B and C terminals, as described previously. However, the ANTICOLLISION RELAY will not be energized; therefore, anticollision will not come on.

18-15. When we move the ANTICOLLISION SWITCH to the FLASH position, power from the flash terminal of the switch is applied to the top section of the FUSELAGE SWITCH. Now, if the FUSELAGE SWITCH is in the BRT position the ANTICOLLISION RELAY will close and the ANTICOLLISION LIGHTS will flash. To sum up, the ANTICOLLISION LIGHTS will come on only when the fuselage lights are on bright and flashing.

18-16. **Fuselage Lights.** The fuselage lights shown on our schematic of exterior lighting systems are not found on all types of aircraft. The circuit for these lights is fairly simple. The switch setting determines whether the lights are bright or dim. They can be made to flash or burn steady at either switch setting. The lamps are of the

double-filament type and the filaments are of different wattage ratings. One of the filaments is energized for bright lights, the other for dim lights. A separate transformer that steps the voltage down to 6 volts from 28 volts is used to energize each filament.

18-17. **Other Exterior Lighting Circuits.** Nearly every type of aircraft has some type of lighting circuit that is peculiar to its configuration, since it is designed to serve a particular purpose. For example, the join-up lights on the F-4C mark the trailing edge of the wingtip as a guide to other aircraft flying formation. Aircraft designed for air refueling have exterior lights marking the refueling receptacle.

18-18. Tanker aircraft are equipped with a rendezvous light system. This system consists of rotating lights on both the bottom and top of the aircraft. They serve as beacons for aircraft approaching for air refueling. Each lamp assembly contains four lights. Two of them reflect a high beam and the other two reflect a low beam. Also, two of the lights are of one color, and the others are another color. By controlling which color and which beam is illuminated, coded signals can be flashed to aircraft in the vicinity.

19. Lighting System Analysis and Maintenance

19-1. A great part of troubleshooting can be eliminated or at least reduced by carefully analyzing an ailing system from technical order schematic diagrams. In most cases involving lighting systems, however, the trouble is a burned-out bulb. This trouble is so common that provisions are made to carry spare bulbs for the light installations that are accessible during flight. It is common practice to change the light bulb before performing any maintenance procedure, except checking to see that the circuit breaker has not opened. It is when changing bulbs does not correct a malfunction that circuit analysis and troubleshooting begin.

19-2. **Circuit Analysis.** In order to analyze circuits you must know the types of circuits, such as whether a circuit is a series, a parallel, or a combination series-parallel circuit. You must recognize the symbols used on schematic and wiring diagrams to denote circuit components.

19-3. Let us use the exterior light system schematic (FO 6) and determine from the diagram what the trouble might be if the taxi light did not come on but, with the switch in the proper position, the landing light lit. We stated above that changing the bulb would often be the first step when trouble developed, but in the case of a large light assembly, such as the taxi light, you would quite likely check it first. To determine the possible reasons for the lamp not burning, you should apply a little logic. We know the control circuit is good from the bus to the switch because that much of the circuit is in common with the landing light. Also, the ground circuit of the relays is good through the L.H. LIMIT SWITCH (GEAR DN). So now the lead from the taxi terminal on the switch to the taxi relay coil, the relay coil, or the lead from "X2" of the TAXI LIGHT RELAY to "X2" of the LANDING LIGHT RELAY might be the trouble. Also, the trouble might be anywhere in the power circuit from the circuit breaker to the ground of the taxi light.

19-4. Before we cover troubleshooting, let's analyze another circuit. Suppose the upper fuselage light did not come on with the switch in the DIM position. You would know, after a brief study, that the trouble was either in the transformer, the bulb, the socket, or the short connecting wires of the dim circuit. In this case, a change of bulbs would probably be the fastest check and, therefore, the first check. If changing bulbs did not correct the trouble, further steps would be necessary.

19-5. Other circuits of the schematic may be analyzed in much the same way as the two simple examples we have discussed. However, since some of the circuits contain more components and are more complicated than these two circuits, in actual practice it would take more time to analyze them. After you have analyzed the system and have determined just what factors could cause a circuit to malfunction in a particular way, you are ready to troubleshoot.

19-6. **Troubleshooting.** If the circuit analysis has been thorough, troubleshooting of the circuit consists of a few simple checks. The checks can be made with either a voltmeter or an ohmmeter. Most mechanics prefer the voltmeter because it is easier to use and is faster, and also because it is not necessary to isolate the circuit to get true readings when it is used. Since the circuit being tested with a voltmeter must have voltage applied when tests are being made, the mechanic must take necessary safety precautions.

19-7. Using the circuit of the taxi light that we analyzed on foldout 6, a voltmeter check at terminal A2 of the relay would show if the relay closed properly. When the relay closed, a voltage would be found between A2 and ground. The mechanic must know and remember the voltage is ac at this point. The next checkpoint would usually be the lamp terminals to ground. Source voltage should be present at the input terminal and there should be no voltage at the ground terminal. If these readings are found but the light does not burn, the bulb is burned out. If voltage is found on the ground side, the ground lead is loose or broken. If zero voltage is found on the

input terminal, an open in the lead going back to the relay is indicated.

19-8. When testing the same circuit with an ohmmeter, you should first open the circuit breaker of the control circuit, and then open the circuit breaker that carries power to the taxi relay contacts. A check with the ohmmeter from the terminal of the switch marked "TAXI" on the schematic drawing to ground should show the resistance of the relay coil. A check from A1 of the relay to the circuit terminal of the circuit breaker should show zero resistance. A check from A2 of the relay to ground would show continuity with the low cold resistance of the taxi bulb. If no continuity is found, check on the input side of the bulb. At this point, continuity indicates an open lead back to the switch. If the meter needle does not deflect, check the ground side of the bulb to ground. A zero reading at that point shows an open bulb; no needle movement or a high reading indicates a broken or loose ground connection. After the trouble is found and corrected, the circuit is restored to an operating condition (circuit breaker closed) and the circuit tested for operation.

19-9. The time needed to analyze, troubleshoot, and repair the lighting circuitry will depend on many things. The skill and experience of the crew that you have available will make a difference in the time involved. The type of aircraft and the circuits which are malfunctioning also will influence the time required for maintenance. It takes longer to replace a component such as a flasher unit that won't operate than it does to replace a light bulb or a faulty circuit breaker.

20. Window Anti-Icing Circuit

20-1. One way of accomplishing window anti-icing and window defogging is by using electrically heated windows. The type of windows used for this purpose are known as Nesa glass windows.

20-2. Aircraft are equipped with Nesa windows in designated areas to provide a means for deicing and window defogging. The Nesa windows installed on one aircraft are basically the same as any other Nesa window you may have worked on. In the event you have had no experience with this type of window, it is a shatterproof window constructed somewhat like a "sandwich," having an inner glass pane, a layer of vinyl plastic, the Nesa compound, and the outer pane. Two bus bars are bonded to the Nesa film on opposite edges of the outer pane. These are joined to two external connectors which come from the ac power supply. To control the heat applied to the window, a temperature-sensing element is imbedded in the vinyl layer of the "sandwich" and connected to a temperature control unit through the proper leads. The window is assembled by inserting the glass "sandwich" into a molded phenolic frame, which is fastened to the aircraft structure with screws and clips.

20-3. **Nesa Windows.** There are basically two types of Nesa windows. One is used for both anti-icing and defogging, and the other is used only for defogging. Both windows are of the sandwich type.

20-4. The windows that provide both anti-icing and defogging have the conductive coating between the outer pane and the vinyl plastic. The defogging windows have the conductive coating between the inner pane and the vinyl plastic.

20-5. **Temperature Control.** The sensing elements embedded in the vinyl plastic layer of the anti-icing and defogging windows provide the necessary temperature regulating.

20-6. This is accomplished by the resistance variations of the sensing elements as a result of window temperature change. This resistance change is transmitted to the controller amplifier and controller bridge rack (fig. 49). The bridge circuit between the amplifier and sensing unit controls the heat of the window by controlling the electrical power to the window. The window heat will be applied when the sensing element resistance is between 330 and 342 ohms. A voltage of 6.3 volts is supplied to the sensing element by a transformer contained in the controller amplifier (fig. 49) to establish the automatic temperature control point. Manual adjustments for the regulation of temperature between 32.3° C., (90° F.) and 54.5° C., (130° F.) are located on the exterior of the controller bridge. There are two adjustments that may be made on the controller amplifier. These adjustments are, accomplished through the TEMPERATURE adjustment potentiometer, which is used to adjust the control point of the temperature desired; and the DIFFERENTIAL adjustment potentiometer, which is used to adjust the width of the temperature range and to provide positive closure of the relay contacts of the amplifier (fig. 49). This is the only maintenance that you can perform on the amplifier while it is installed on the aircraft, so if these two adjustments do not correct the trouble, replace the unit.

20-7. In some cases the Nesa window's electrical resistance will increase with age It is possible to have an overheat condition occur in a Nr. 2 window if a resistance increase should take place in the mating Nr. 1 window. Therefore, the resistance of the windows should be checked at 6 month intervals. The procedure for this check will be explained at the end of this section.

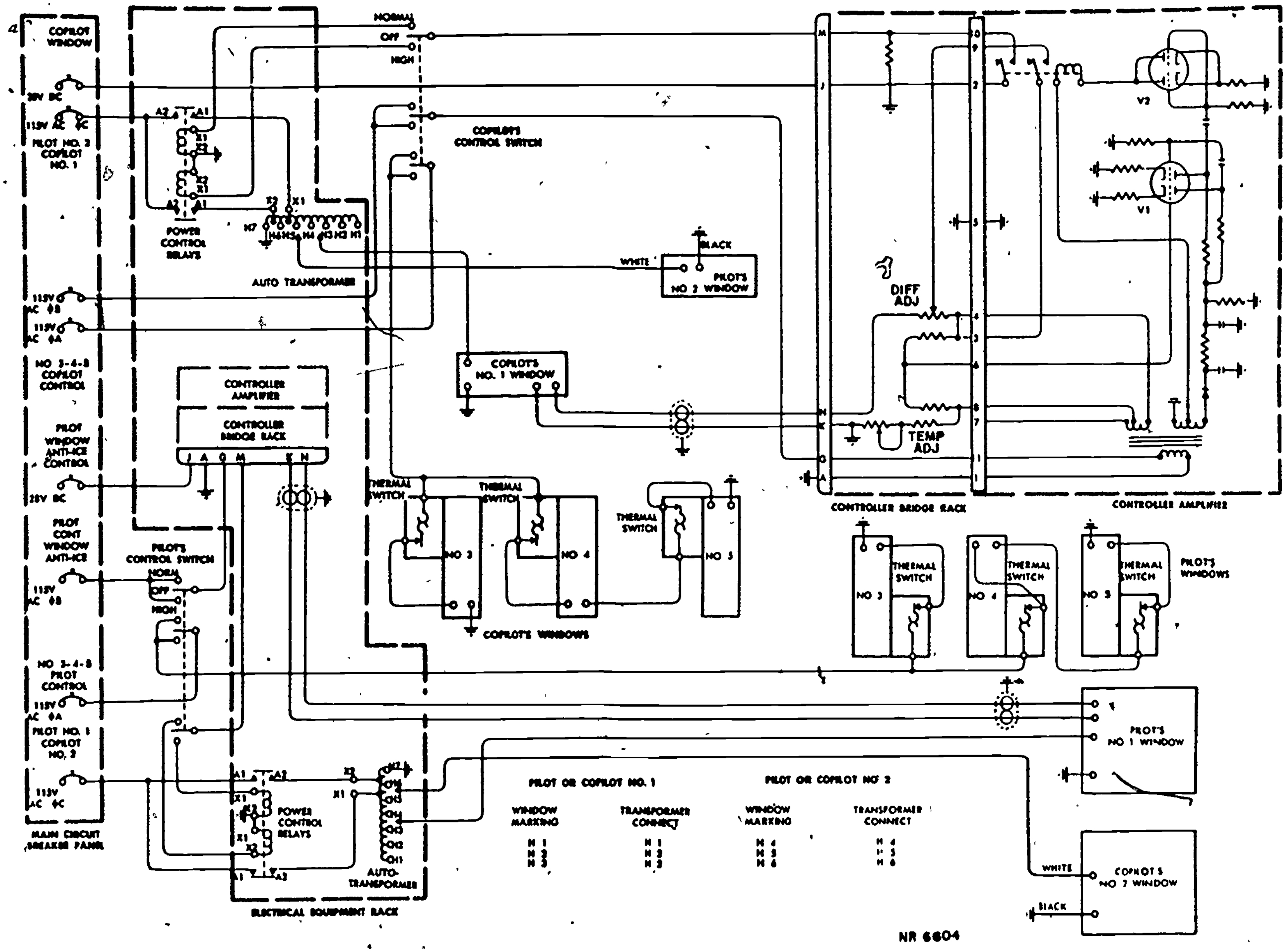

Figure 49. Window anti-icing circuit.

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20-8. The temperature control circuit for the defog windows is somewhat different from that previously discussed for the anti-icing windows. The temperature for these windows is controlled by individual thermal snap switches.

20-9. The thermal switch face is held in contact with the inner pane by means of a torsion spring on the switch bracket. A marked arrow is provided on the window edge to enable the thermal switch to be placed in the proper position. The switch is an SPST switch rated at 115 vac at 380 to 1000 cycles. The contacts are normally closed and have a control point of approximately 100° F.

20-10. The thermal snap switches for the defog windows are connected to a 115 vac source and provide a window heating voltage of approximately 7 vac to the Nr. 4 windows (fig. 49) and 45 vac to the Nr. 5 windows. The Nr. 3 windows are in parallel with the 4 and 5 combinations. as shown in figure 49.

20-11. **Operation.** The electrical system uses 28 vdc and 115 vac. The 28 vdc circuit (see fig. 49) merely supplies power to close an ac power relay. You will note in figure 49 that the ac relay, when closed, completes a circuit to the autotransformer; the 115 vac to this transformer is stepped up to approximately 250 vac in the LOW selection of power. This increased voltage applied directly to the Nesa window causes it to heat. In the HIGH switch position, the voltage from the transformer is approximately 400 volts. The window temperature range itself is not affected by either type of voltage applied; the higher voltage merely allows the window to reach the proper temperature sooner.

20-12. Perhaps, at this point, we should caution you about selecting the voltage that you apply to the window. You should always place the control switch, which is a gang type switch, in the LOW position and allow a 15-minute warmup period before moving it to the HIGH position. You can easily see that initially selecting the HIGH position without allowing the 15-minute warmup period might bring on real trouble. A rapid application of heat to a cold window surface might easily break the glass. After the warmup period, you can move the switch to the HIGH position. The HIGH switch position is needed only during extreme icing conditions. You will find that for purposes of normal operation the switch can stay in the LOW position.

20-13. If you look at figure 49 for a moment, you will notice that the anti-icing windows contain sensing elements. The resistance of this element is the fourth leg of a Wheatstone bridge. When the element is cold, its resistance is such that the bridge circuit becomes unbalanced. When this happens, a signal appears at the amplifier, where it is amplified and sent on to energize the amplifier control relay. You will notice by tracing through the circuit that when the amplifier control relay closes, the dc circuit is completed to the ac power relay, which allows ac power to be applied to the window. When power is applied to the window, the temperature-sensing element embedded in the window begins to absorb heat from the warming Nesa compound and starts to change its resistance. When the temperature of the glass surface reaches the desired setting, the resistance of the sensing element is such that the bridge circuit is balanced. This cancels the signal to the amplifier and shuts off the heat. When the window cools to a point at which the bridge circuit again becomes unbalanced, the cycle is repeated. Perhaps you are wondering what the temperature of the Nesa glass is under operating conditions. Usually the sensing element unbalances the bridge circuit when the temperature drops below 100° F. (43.4° C.).

20-14. **Operational Check.** For a satisfactory operational check, the ambient temperature should not be above 75° F. All the window leads should be connected to the proper transformer terminals (see table 3). When the sensing leads from the pilot's window Nr. 1 and the power leads from pilot's Nr. 1 and copilot's Nr. 2 windows are disconnected, a 0- to 500-vac volt-

TABLE 3

PILOT'S AND COPILOT'S WINDOW VOLTAGES

	Window Terminal Marking	*Transformer Terminal Marking*	*Resistance in Ohms*	*Volt (Approx) Window Heat Control Switch Normal*	*Volt (Approx) Window Heat Control Switch High*
Pilot or Copilot Window Nr 1	H1 H2 H3	H1 H2 H3	43.8–48 39.6–43.8 35.4–39.6	220 216 200	307 293 278
Pilot or Copilot Window Nr 2	H4 H5 H6	H4 H5 H6	66.6–72.9 60.2–66.6 53.9–60.2	183 175 166	254 243 232

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meter is placed across the power leads of window Nr. 1 and a similar voltmeter is placed across the power leads of window Nr. 2. A 0- to 400-ohm resistance box set at 342 ohms is placed across the sensing leads. With external power connected and the window heat control switch moved to the NORMAL position, the voltmeter should read zero. When the variable resistance on the box is reduced to 330 ohms, the voltmeter should read in accordance with the chart in table 3. Resistance of both windows is measured with power off. If the resistances are within the ranges corresponding to the values shown in table 3, the windows are satisfactory. A resistance check of the sensing element should be made if no voltage appears or if the controller does not operate to reduce the voltage to zero within 2 minutes with an ambient temperature of 70° F. or greater. If the controller works satisfactorily and the window heat control switch is placed in the HIGH position, the voltage should read in accordance with column 5 of table 3 when the controller power cycle is on. It is important that the windows are not damaged due to overheat. The thermal switch should operate to remove power from the window in approximately 10 minutes, if the temperature is 70° F. The applicable TO will give specifications of an operational check for a particular window.

20-15. **Troubleshooting.** When troubleshooting the window anti-icing circuits, you should be extra cautious. There are some very high voltages in this system that could be dangerous to both personnel and equipment.

20-16. Referring to figure 49, if Nrs. 4 and 5 pilot's windows are inoperative and Nr. 3 window is operating satisfactorily, the probable cause is a defective thermal switch or wire. A test of the thermal switch on Nr. 4 window should indicate continuity. If there is no continuity, the thermal switch is defective and should be replaced. There should be continuity reading of the wiring from Nr. 4 switch through Nr. 5 switch. If there is no continuity, an open circuit exists, and all defective wiring should be repaired or replaced. Now let us suppose that the copilot's set of windows fails to heat with the control switch in any position. There are several things that could cause this trouble: the circuit breaker, the sensing element, the temperature controller, the autotransformer, or the control switch. The circuit breakers should be closed (pushed in) and serviceable. After disconnecting the leads to the sensing element at the window, a reading of continuity of the element should be present. If there is no continuity, the element is defective and should be replaced. Substituting a new controller amplifier and/or controller bridge rack will determine whether or not the original controller is defective. Disconnecting either X_1 or X_2 lead from the autotransformer and applying 115-vac, 400-cycle power directly to the unit will determine the status of the autotransformer. High voltage will be present, and extreme caution must be observed. Refer again in the text to table 3, "Pilot's and copilot's window voltages." This load voltage from H1 through H6 should agree with those given in table 3; if not, replace the defective autotransformer. The control switch should read continuity across the switch terminals of its respective NORMAL or HIGH position. If there is no continuity on either check, the switch should be replaced. There should be continuity of wiring between each component. If the resistance is infinite, then repair or replace all defective wiring. This concludes our discussion of troubleshooting the miscellaneous control circuits.

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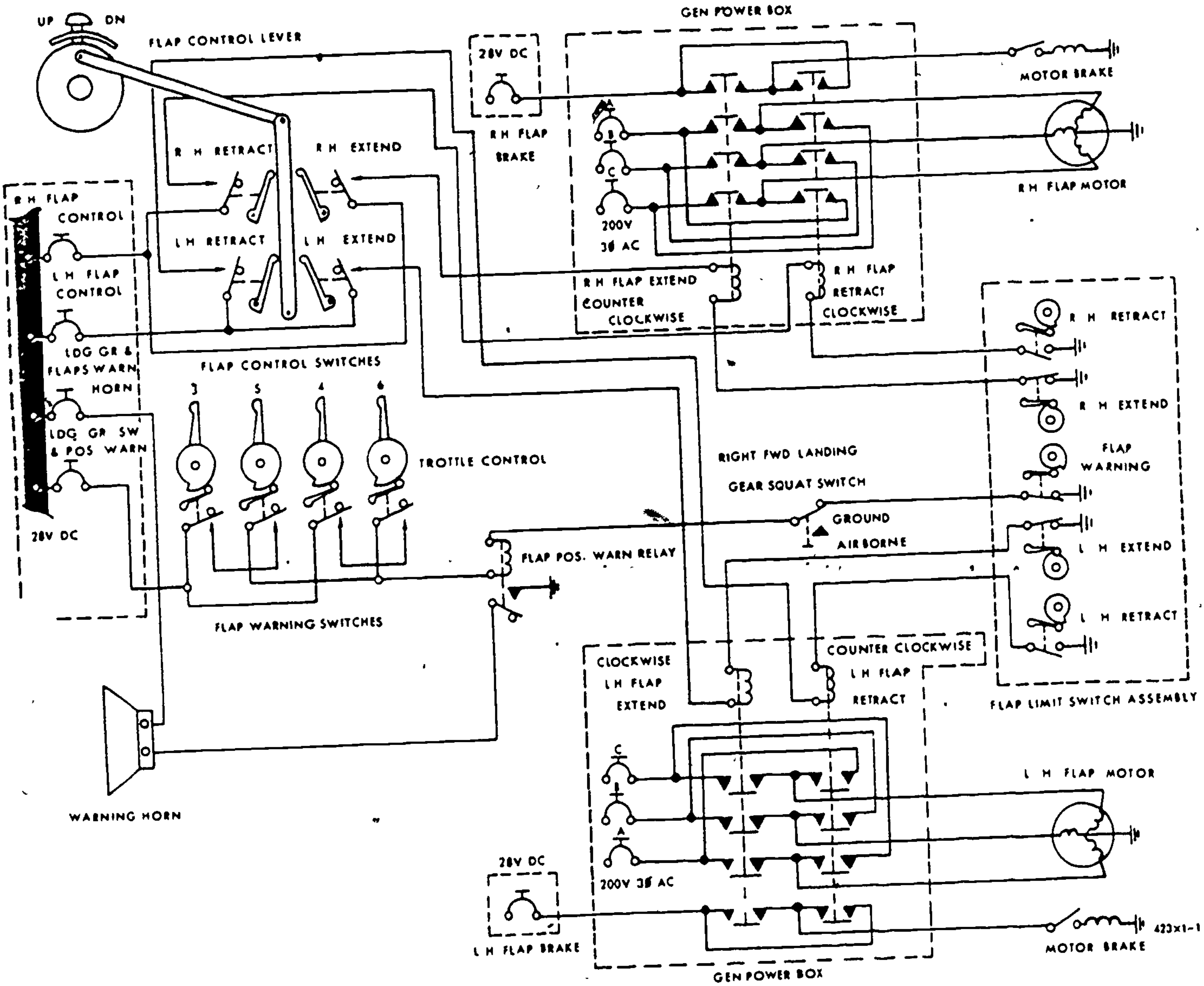
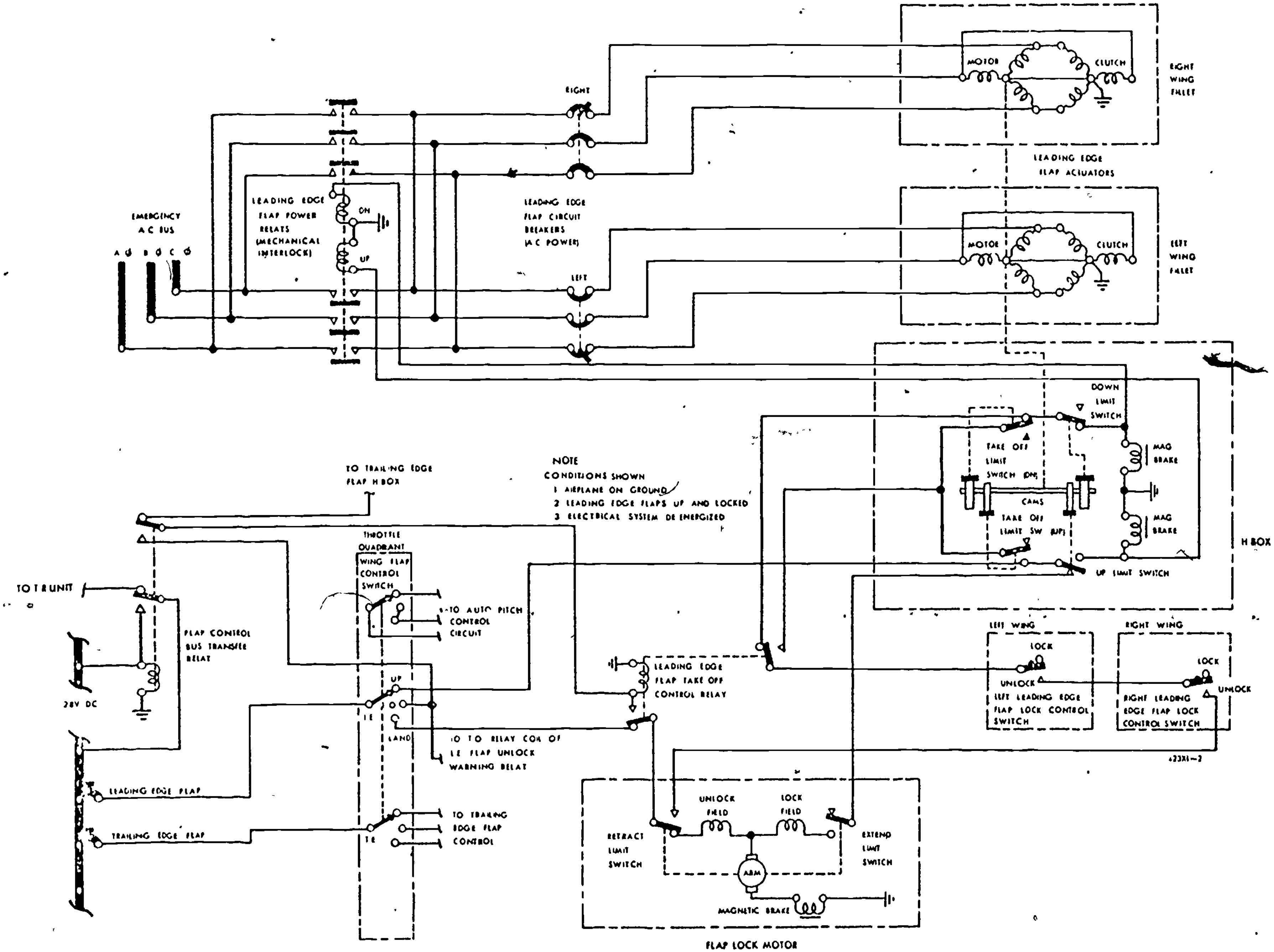
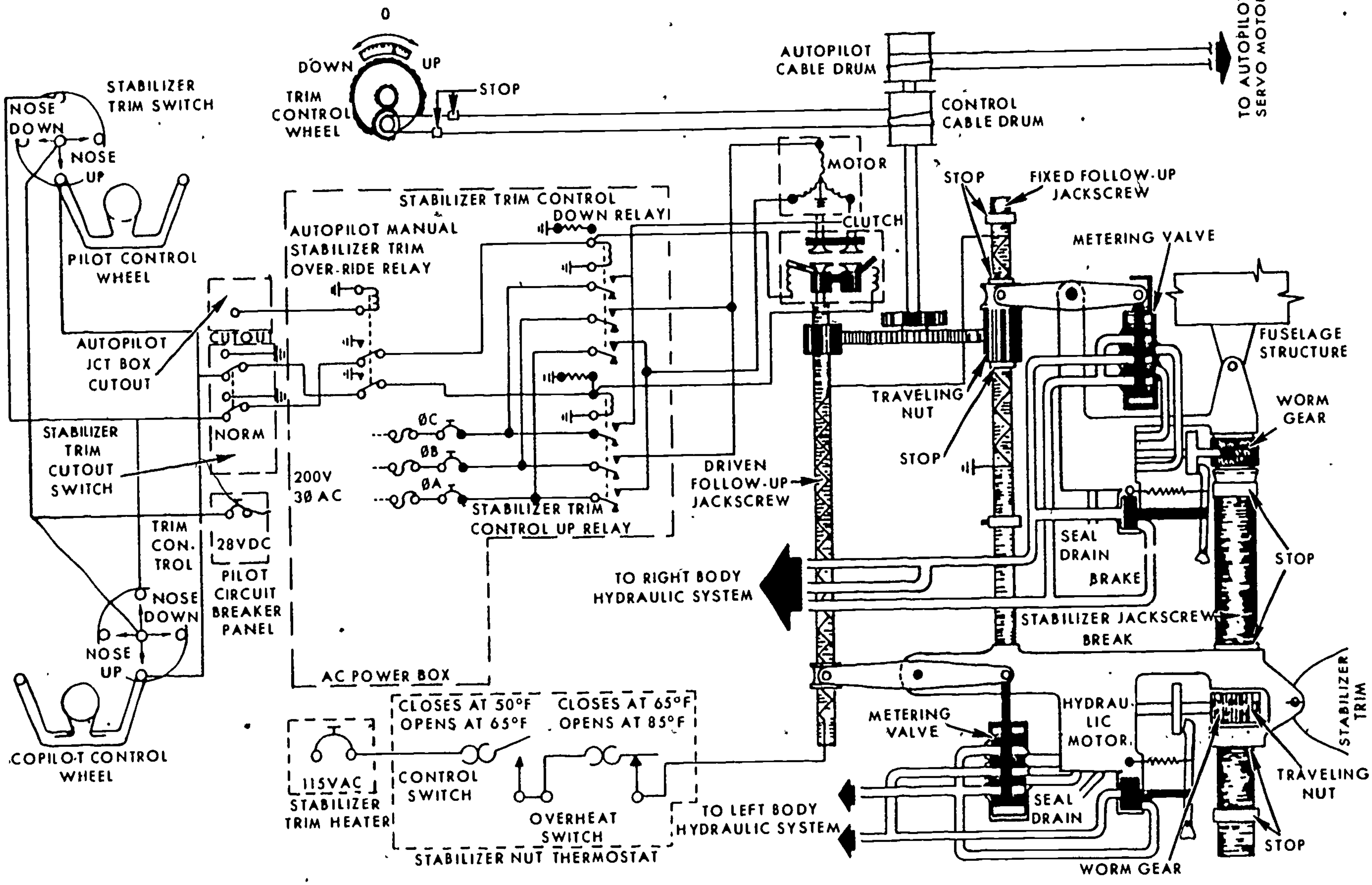


Foldout 1. Wing flap control circuits.



Foldout 2. Wing leading-edge flap actuator control circuit.



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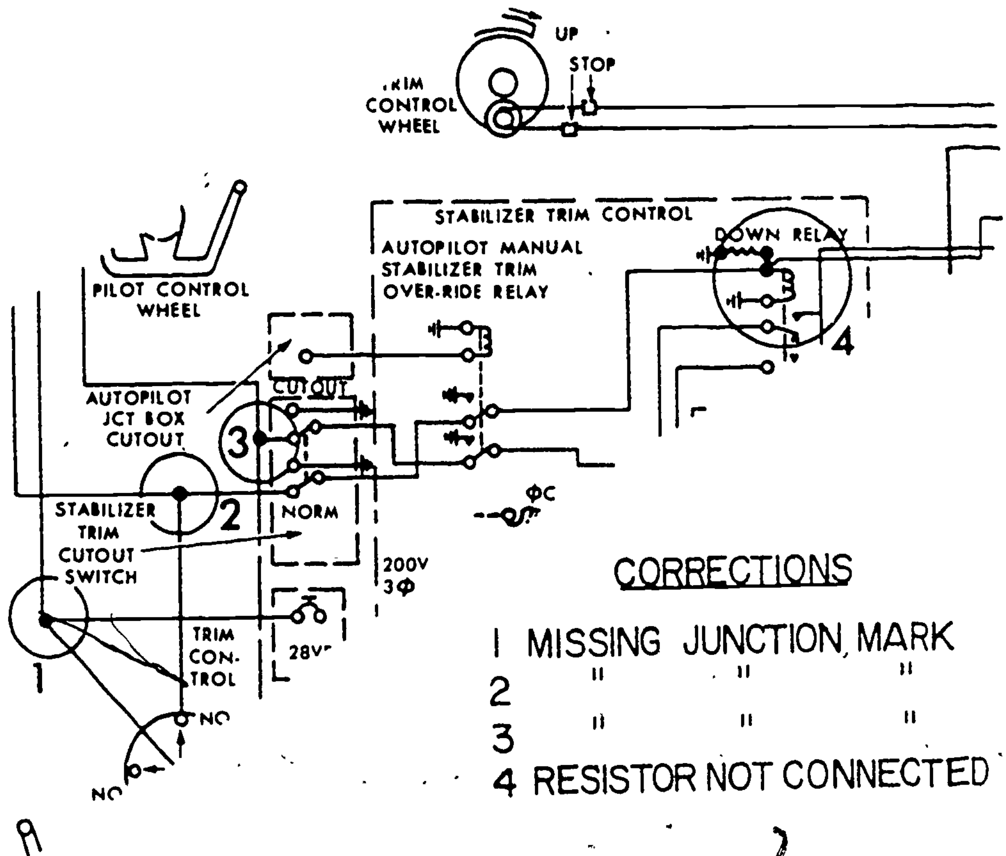
Foldout 3. Stabilizer trim control circuits.



CORRECTIONS

1 MISSING JUNCTION MARK
2 " " "
3 " " "
4 RESISTOR NOT CONNECTED

NOTE to Student: Make the above corrections in Foldout 3, CDC 42351, Volume 3.

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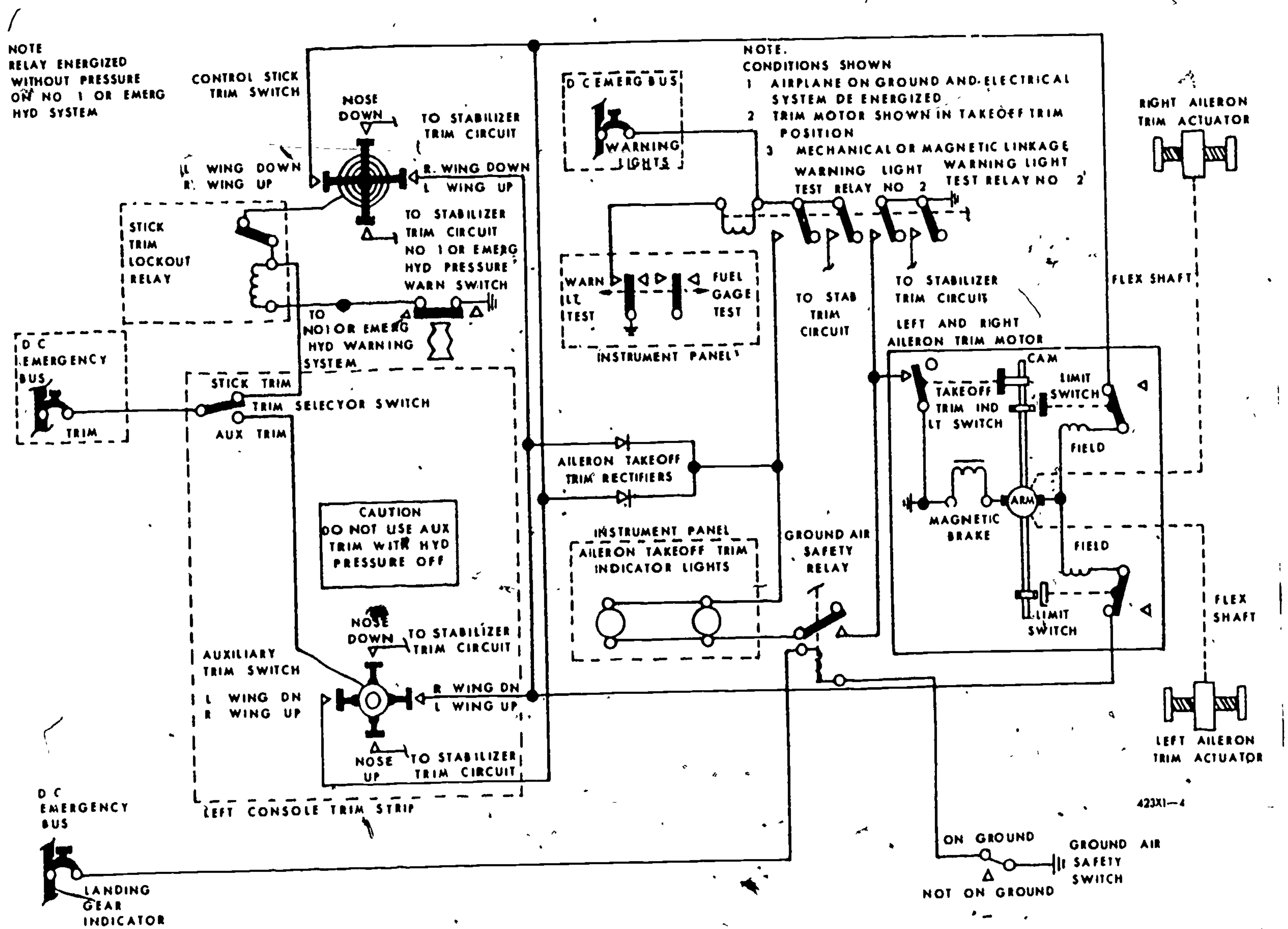
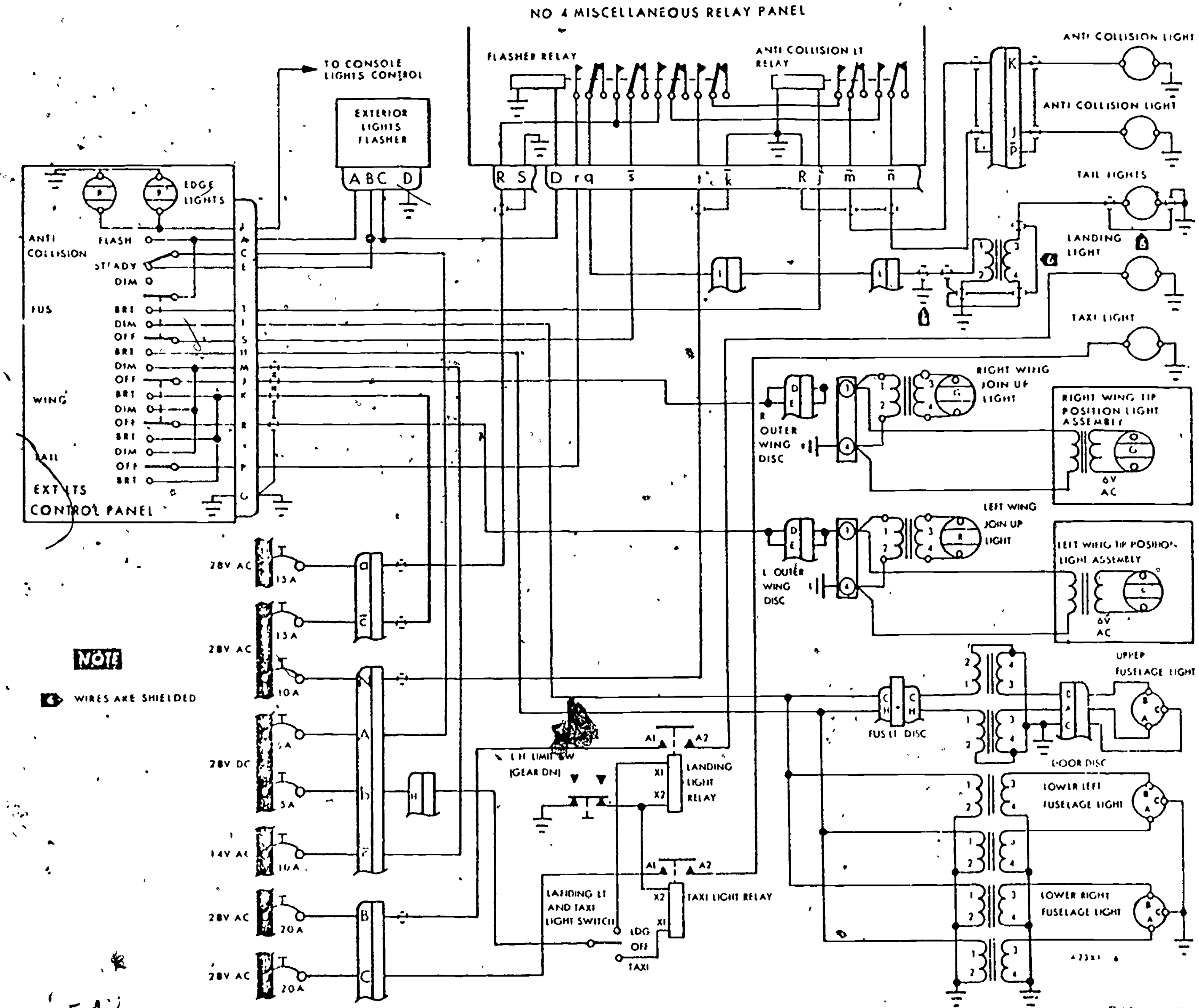


Foldout 4. Aileron trim control circuits

MODIFICATIONS

Foldout 5 of this publication has (have) been deleted in adapting this material for inclusion in the "Trial Implementation of a Model System to Provide Military Curriculum Materials for Use in Vocational and Technical Education." Deleted material involves extensive use of military forms, procedures, systems, etc. and was not considered appropriate for use in vocational and technical education.



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Foldout 6. Exterior lights.

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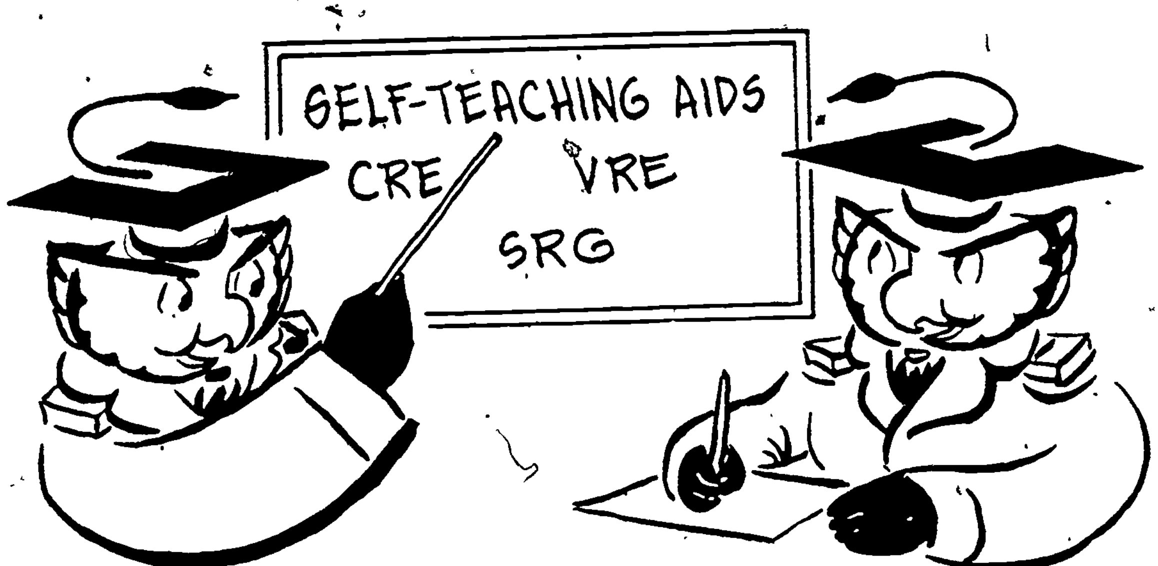
WORKBOOK

Aircraft Electrical Repairman



This workbook places the materials you need *where* you need them while you are studying. In it, you will find the Study Reference Guide, the Chapter Review Exercises and their answers, and the Volume Review Exercise. You can easily compare textual references with chapter exercise items without flipping pages back and forth in your text. You will not misplace any one of these essential study materials. You will have a single reference pamphlet in the proper sequence for learning.

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STUDY REFERENCE GUIDE

1. *Use this Guide as a Study Aid.* It emphasizes all important study areas of this volume.

2. *Use the Guide as you complete the Volume Review Exercise and for Review after Feedback on the Results.* After each item number on your VRE is a three digit number in parenthesis. That number corresponds to the Guide Number in this Study Reference Guide which shows you where the answer to that VRE item can be found in the text. When answering the items in your VRE, refer to the areas in the text indicated by these Guide Numbers. The VRE results will be sent to you on a postcard which will list the *actual VRE items you missed.* Go to your VRE booklet and locate the Guide Number for each item missed. List these Guide Numbers. Then go back to your textbook and carefully review the areas covered by these Guide Numbers. Review the entire VRE again before you take the closed-book Course Examination.

3. *Use the Guide for Follow-up after you complete the Course Examination.* The CE results will be sent to you on a postcard, which will indicate "Satisfactory" or "Unsatisfactory" completion. The card will list *Guide Numbers* relating to the questions missed. Locate these numbers in the Guide and draw a line under the Guide Number, topic, and reference. Review these areas to insure your mastery of the course.

Guide Numbers 300 Through 322

Guide Number	
300	Introduction to Landing Gear and Associated Systems; Heavy Aircraft Landing Gear System: General; Landing Gear Lever Lock Circuit; Landing Gear Position and Warning System, pages 1-4
301	Heavy Aircraft Landing Gear System: Antiskid Control Circuit, pages 4-9
302	Fighter Aircraft Landing Gear System, pages 9-14
303	Introduction to Flight Control Electrical Systems; Wing Flap Control Circuits, pages 15-18
304	Stabilizer Trim Control Circuit; Aileron Trim Control Circuit, pages 18-20
305	Introduction to Warning Circuits; Fire and Overheat Warning: Thermal Switch Circuit, pages 21-24
306	Fire and Overheat Warning: Thermocouple Fire Warning Circuit; Photoelectric Circuit, pages 24-27
307	Fire and Overheat Warning: Continuous Cable Circuit, pages 27-30
308	Master Warning and Caution System; Bailout Warning System, pages 31-36
309	Troubleshooting and Warning Circuits, pages 36-38
310	Introduction to Fuel Systems; Main Fuel Systems: System Components, pages 39-44
311	Main Fuel Systems: Operation, pages 44-45
312	Air Refueling Circuits; Fuel Scavenge Circuits, pages 45-48
313	Introduction to Power Plant and Related Control Circuits; Starter Systems: General; DC Starters, pages 49-51
314	Starter Systems: Fuel-Air and Pneumatic Starters, pages 51-57
315	Starter Systems: Maintenance of Starter System Components, pages 57-59
316	Auxiliary Components, pages 59-62
317	Ignition Systems: TEN-1 Ignition System; Nonregulated and Regulated Systems, pages 62-65
318	Ignition Systems: Operation of TEN-1 Systems; TFN-6 Ignition System, pages 65-69
319	Related Power Plant Control Systems, pages 69-72
320	Introduction to Utility Systems; Interior Lighting Systems, pages 73-76
321	Exterior Lighting Systems; Lighting System Analysis and Maintenance, pages 76-79
322	Window Anti-Icing Circuit, pages 79-82

CHAPTER REVIEW EXERCISES

The following exercises are study aids. Write your answers in pencil in the space provided after each exercise. Immediately after completing each set of exercises, check your responses against the answers for that set. Do not submit your answers to ECI for grading.

Chapter 1

Objective. To be able to recognize important characteristics of landing gear systems, including the landing gear control panel and the landing gear position and warning system, and of the antiskid system, including the skid detector and the antiskid control valve.

1. What is the purpose of the landing gear lever lock circuit? (1-4)

2. When does the red warning light in the gear control lever illuminate? (1-9)

3. If a gear is up and locked, but the indicator shows an intermediate position, what is the most probable cause of trouble? (1, Pars. 10 and 15) (1-10)

4. While a gear is extending or retracting, what is the indication on the position indicator for that gear? (1-10)

5. How is the ground circuit for gear position indicators completed? (1-14)

6. What is the purpose of the main gear load switches? (2-10)

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7. When is the control coil of the fairing door safety relay energized? (2-10; Table 1)

8. What is the purpose of the holding coil of the fairing door safety relay? (2-10; Table 1)

9. When are the gear sequence switches actuated to the CLOSED position? (Sec. 2, Pars. 10 and 11) (2-10, 11)

10. Why is it necessary to have a sequencing circuit in a landing gear system? (2-24)

Chapter 2

Objective. To show knowledge of electrical circuits associated with flight control systems, including circuitry involved in wing flap systems and in stabilizer and aileron trim control systems.

1. How does the wing flap motor change its direction of rotation in the wing inboard and outboard flap system? (3-4)

2. Why is it necessary to have an internal brake in the flap motor? (3-5)

3. When will the wing flap warning circuit cause the warning horn to sound? (3-7)

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4. What prevents further operation of the leading-edge flaps once the flap lock actuator is in the LOCKED position? (3-11, 12)

5. What is the purpose of the leading-edge flap H-BOX? (3-12, 15)

6. How are the leading-edge FLAP POWER DOWN and UP RELAYS energized and deenergized? (3-15, 17)

7. In cleaning an actuator, what is used to wash all nonelectrical parts? (3-21)

8. What is the purpose of the stabilizer trim heater? (4-9)

9. In the aileron trim control circuit, what prevents the aileron takeoff trim indicator lights from operating when the aircraft is airborne? (5-8, 9)

10. During an operational checkout of the aileron trim system, what two systems must be powered? (5-10)

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Objective: To demonstrate knowledge of the systems used to warn of fire and overheat conditions, including the thermal switch, thermocouple, photoelectric, and continuous cable systems, and of the master warning and caution circuit.

1. Name the four different types of fire detection systems currently in use on AF equipment. (6-1)

2. How does a thermal switch operate? (6-5)

3. Into what three circuits is the thermocouple fire warning detection system divided? (6-16)

4. How does the thermocouple operate in a warning system? (6-18)

5. Why is it important that a polarity check of a thermocouple fire detector system be made? (6-21)

6. At what frequency range will the photoelectric circuit become activated to cause the warning lights in a photoelectric fire warning system to illuminate? (6-22)

7. How does the sensing loop in a continuous cable fire warning system operate? (6-29)

8. What is the purpose of the master warning and caution system? (7-1)

9. In the master warning and caution system, what is the purpose of the ground protection relay? (7-17)

10. What are the two conditions in the master warning and caution system under which the master warning lamp will go out? (7-14, 19)

11. What is the purpose of the takeoff warning circuit? (7-23)

12. What is the purpose of an annunciator panel? (7-24)

13. What causes the photocell unit to activate in a smoke detector warning circuit? (7-24)

14. In the emergency alarm bell and warning horn circuit, what is the purpose of the capacitor in parallel with the master alarm bell? (7-26)

15. In the door warning circuits, how is each indicator circuit completed? (7-27)

16. In the door warning circuits, what two things most occur for the warning light not to illuminate? (7-27)

17. In the bailout warning system, what are the different warnings available to each crewmember before he ejects? (8-1)

18. In the bailout warning system, what is the indication for the pilot when all the crewmembers have ejected? (8-1)

19. What determines the troubleshooting procedure for the master warning and caution system? (9-2)

Chapter 4

Objective: To understand main fuel system components and the air refueling and fuel scavenge circuits.

1. In the fuel system, what information is found on the boost pump? (10-5)

2. Of the three types of fuel valves discussed in the fuel system, which type is generally found as a fire shutoff valve? (10-7)

3. What is the purpose of a fuel level control valve? (10-13)

4. In the air refueling control system, what is the function of the induction coil at the air refueling receptacle? (11-4)

5. What is the purpose of a fuel scavenge system? (12-1)

Chapter 5

Objective. To demonstrate knowledge of the engine starter and ignition systems and the control circuits of the oil cooler flap actuater, cowl flaps, and water injection systems.

1. What is the relationship between torque and current in a series starter motor? (13-5)

2. What is the effect of reducing the field flux of a series dc motor? (13-8)

3. When does the pressure switch in the compressor circuit of the fuel-air starter operate? (13-20)

4. What two sources can be used to operate a conventional pneumatic starter? (13-26)

5. What is the effect of an open centrifugal switch in the pneumatic starter discussed in the text? (13-31)

6. What protective device guards the cartridge pneumatic starter against overpressure conditions? (13-37)

7. Is it possible to ignite the pressure-relief squib on the cartridge starter during a low-pressure start? (13-42)

8. Why is it necessary to use more than one torquemeter on the Prony brake? (13-56)

9. What is the effect of grounding the p lead (primary lead) of a magneto? (14-5)

10. What is the primary difference between an aircraft ignition switch and a conventional ignition switch? (14-11)

11. What is the difference between a regulated and a nonregulated TEN system? (15-6, 7)

12. What is the output voltage of the nonregulated system dynamotor? (15-10)

13. What is meant by "generator action"? (15-14)

14. Why are capacitors C6 and C7 used in both the regulated and nonregulated TEN ignition systems? (15-11, 15)

15. What is a major difference between the regulated and nonregulated TEN system? (15-15)

16. In the TEN-1 system, when does the igniter plug cease conducting? (15-25)

17. How is the sparking rate of the TEN-1 system increased? (15-30)

18. What three systems are used to maintain proper engine temperature? (16-1)

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19. What system is used to control the flow of air around the cylinders? (16-2)

20. What prevents the actuator motor from coasting when the switch is opened? (16-3)

21. What device stops the actuator if the control switch is left in the OPEN Position? (16-4)

22. What must happen to air flow if engine temperature is to increase? (16-5)

23. What circuit component allows the pilot to stop the cowl flaps within their limits of travel? (16-7)

24. What causes current to flow in the micro positioner coil? (16-8)

25. What component could be added to this system to make it automatic? (16-9)

26. What controls the linear movement of the oil cooler flap actuator? (16-11)

27. What releases the magnetic brake in the oil cooler flap actuator? (16-13)

28. What components provide radio noise free operation in the oil cooler flap actuator? (16-15)

29. What is injected in to an engine to prevent detonation? (16-17)

30. What supplies ADI system pressure? (16-18)

31. Electrical power for ADI circuits comes from what source? (16-19)

Chapter 6

Objective. To apply understanding of the operation, circuit analysis, and troubleshooting procedures of aircraft lighting systems and Nesa window system.

1. Why does a bomber or cargo type aircraft require more lighting systems than a fighter aircraft? (17-1)

2. How are instruments illuminated if the primary instrument lighting system fails? (17-2)

3. If the secondary winding of the autotransformer shown in figure 47 were open, which lights would be affected? (17-3; Fig. 47)

4. Why do some cockpit instrument floodlights have red lenses? (17-4)

5. Why are the white instrument floodlights connected to the dc bus system? (17-5)

6. How does pushing the pushbutton switch on the utility light affect its brilliancy? (17-6)

7. What type of lights would you be likely to find on cargo-type aircraft that would not be on fighter-type airplanes? (17-8)

8. What special use is sometimes made of the wheel well lights on large aircraft? (17-10)

9. How do the landing and taxi lights differ in overall purpose from such lighting systems as the formation lights and position lights? (18-1)

10. What feature in the nosegear landing light circuit in most aircraft prevents the landing light from being turned on accidentally? (18-3)

11. In order to have an effective crosswind landing light, what must be true of the front wheels? (18-4)

12. How are the wing taxi lights of some tanker planes used other than for taxi operations? (18-8)

13. If you see a night-flying aircraft with a green wing light to your right, is the aircraft going away or coming toward you? (18-9)

14. Why are some lights switched from a bus that provides 28 volt ac to a bus that has only 14 volt ac applied to it? (18-10)

15. What provision is made for opening and closing the flasher contacts. (18-12)

16. Why are ANTICOLLISION LIGHTS designed to flash whenever they are used? (18-13)

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17. Why is the circuit breaker for one of the ANTICOLLISION LIGHTS of larger capacity than the circuit breaker for the other ANTICOLLISION LIGHT? (18-14)

18. In the fuselage light system discussed in this chapter, what happens when the lights are switched from LIGHT to DIM? (18-16)

19. How does a tanker-type aircraft produce a coded signal for aircraft attempting a rendezvous for air refueling? (18-18)

20. When checking a circuit with an ohmmeter, why must the section being checked be isolated from the rest of the circuit? (19-6)

21. If a voltmeter indicates a voltage on the ground side of a component, what trouble is indicated? (19-7)

22. How is a Nesa window constructed in a window anti-ice system? (20-2)

23. In the Nesa window anti-ice circuit, what is the function of the controller amplifier? (20-6)

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24. What is the purpose of a thermal switch in the Nesa window anti-icing circuit? (20-14)

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ANSWERS FOR CHAPTER REVIEW EXERCISES

Chapter 1

1. The landing gear lever lock circuit prevents accidental operation of the landing gear on the ground. In addition, the lock circuit prevents retraction of the gear unless the gear trucks are level, the nose gear is centered, and the weight of the aircraft is off the gear. (1-4)

2. The warning light in the gear control lever is illuminated when a gear position does not agree with the position of the control lever or when one of the main gear doors is open. (1-9)

3. The most probable cause of trouble when a position indicator shows an intermediate position when the gear is up and locked is a faulty indicator or no power applied to the indicator. (Sec. 1, Pars. 10 and 15) (1-10)

4. When a gear is neither in the up-and-locked nor down-and-locked position, the indicator shows a "barber pole" condition. (1-10)

5. The ground circuit for the position indicator is completed through the related lock switch. (1-14)

6. The main gear load switches are used to prevent retraction of the gear when the gear struts are compressed by the weight of the aircraft. (2-10)

7. The control coil of the fairing door safety relay is energized when all gears are up and locked and all doors are closed and locked. (2-10; Table 1)

8. The holding coil of the fairing door safety relay denergizes the control coil of that relay after all the wheel doors are closed and locked. (2-10; Table 1)

9. The gear sequence switches are actuated to the closed position when the related wheel fairing doors are fully open. (2-10, 11)

10. The sequencing system provides for proper cycling of the landing gear. Remember: The doors must open or close and the gear move up or down in the proper sequence to prevent damage to the components. (2-24)

Chapter 2

1. The wing flap motor changes its direction of rotation by reversing the phase sequence by means of relays. (3-4)

2. The purpose of the brake is to hold the flaps in a fixed position when the motor is not operating. (3-5)

3. The wing flap warning circuit will cause the warning horn to sound when the airplane is on the ground and the following condition exists: the flaps are not fully extended and either the number 3 and number 5 or the number 4 and number 6 throttles are advanced beyond the IDLE position to a point that closes the throttles' control warning switches. (3-7)

4. When the flap lock actuator is in the LOCKED position, the lock control switches open, thus preventing any further operation of the leading-edge flaps. (3-11, 12)

5. The purpose of the leading-edge flap H-BOX is to limit the flap operation by the limit switches and to stop the flap travel by means of the magnetic brakes. (3-12, 15)

6. The leading-edge FLAP POWER RELAYS are energized by moving the flap control lever to the UP, TAKEOFF, or LAND position and deenergized by the UP LIMIT SWITCH or DOWN LIMIT SWITCH in the H-BOX. (3-15, 17)

7. When cleaning an actuator, wash all nonelectrical parts in an approved cleaning solvent. (3-21)
8. The stabilizer trim heater prevents the FOLLOW-UP JACKSCREWS from icing. (4-9)
9. The ground-air safety relay prevents the aileron takeoff trim indicator lights from operating when the aircraft is airborne. (5-8, 9)
10. During an operational checkout of the aileron trim system, the electrical system and the hydraulic system must be powered. (5-10)

Chapter 3

1. The four different types of fire detection systems in use are the thermal switch, the thermocouple, the photoelectric type, and the continuous cable. (6-1)
2. A thermal switch operates when the temperature is so intense that it causes the metal to expand sufficiently to allow the switch contacts to close. (6-5)
3. The three parts of a thermocouple fire warning circuit are the detector, the alarm, and the test circuit. (6-16)
4. When the temperature rises rapidly enough it causes the thermocouple to produce voltage. This causes current to flow in the circuit that energizes the sensitive relay, which in turn closes the slave relay and completes a circuit to the warning light. (6-18)
5. The polarity check is important because a reversed thermocouple will not only fail to operate the system but it will have a tendency to counteract the output of other correctly connected thermocouples. (6-21)
6. The frequency range that will cause the photoelectric circuit to become activated in a photoelectric fire warning system is between 7 and 60 cycles per second. (6-22)
7. A rise in ambient temperature causes the resistance between the center conductor and the outer conductor of the sensing loop to decrease. The resistance of the sensing loop is part of a bridge circuit, and once the bridge circuit becomes unbalanced due to a change in resistance, current will flow, causing the warning light to illuminate. (6-29)
8. The purpose of the master warning and caution system is to inform the pilot of a malfunction in the aircraft by means of a warning light. (7-1)
9. The ground protection relay in the master warning and caution system opens the ground circuits for the master warning and caution system lamps when external power is applied to the aircraft. (7-17)
10. The master warning lamp will go out when the lamp assembly is pushed and will remain out until a different individual warning lamp signals trouble within its system, also the lamp will go out automatically when the individual fault has been corrected. (7-14, 19)
11. The takeoff warning circuit indicates when the aircraft is ready for flight by monitoring relays, such as doors open, spoilers closed, thrust-reverser, flap position takeoff, and horizontal trim relay. (7-23)
12. An annunicator panel identifies an individual warning circuit by its respective lamp's illuminating when a fault occurs. (7-24)
13. The photocell unit will activate in a smoke detector warning circuit when enough smoke in the air causes reflection of the beam of light, normally in parallel with the face of the photocell, to make direct contact on the photocell. (7-24)
14. In the emergency alarm bell and warning horn circuit, the purpose of the capacitor in parallel with the master alarm bell is to prevent arcing at the bell contacts. (7-26)

15. In the door warning circuits, each indicator will illuminate when its respective limit switch completes a ground. (7-27)

16. For the door warning light not to illuminate (1) door must be closed and (2) door must be latched. (7-27)

17. In the bailout warning system, the different warnings available to each crewmember before he ejects are the flashing amber signal light for alert and the steady red signal light for warning. (8-1)

18. When all the crewmembers have ejected, the red CREW HAS EJECTED signal light illuminates. (8-1)

19. The troubleshooting procedure for the master warning and caution system is based upon an operational checkout. (9-2)

Chapter 4

1. The information on the boost pump indicates a 115/200-volt, 400-cycle, three-phase, ac induction motor. (10-5)

2. The motor-driven sliding-gate-type valve is generally used as a fire shutoff valve. (10-7)

3. A fuel level control valve admits fuel into each tank and automatically shuts off the fuel flow when the tank is full. (10-13)

4. The induction coil at the air refueling receptacle in an air refueling control system transfers a disconnect signal from the tanker to the receiver so that an automatic disconnect will take place. (11-4)

5. The purpose of a fuel scavenge system is to remove fuel trapped in the manifold by air-refueling in flight or single-point refueling on the ground. (12-1)

Chapter 5

1. In a series dc motor, the torque produced is proportional to the square of the current in the armature. (13-5)

2. When the field flux of a dc series motor is decreased, the motor speed must increase in order to produce the cemf required to prevent the motor from overspeed. (13-8)

3. The pressure switch in the compressor circuit of the fuel-air starter closes when the pressure in the air bottle decreases below 2800 ± 100 psi. (13-20)

4. A conventional pneumatic starter may be operated by an external air source or by air bled from an operating engine on the aircraft. (13-26)

5. If a centrifugal switch in the pneumatic starter is open, the ground for the starter control valve is broken and the starting cycle is terminated. (13-31)

6. The safety disc of the cartridge pneumatic starter ruptures to vent cartridge gas into the exhaust in the event the breech pressure becomes excessive. (13-37)

7. No. The pressure-relief squib cannot be ignited during a low-pressure start because the selector switch is in the low-pressure position. (13-42)

8. Two torquemeters are used in the Prony brake to check both right-hand and left-hand rotations. (13 56)

9 When the p lead of a magneto is grounded, ignition does not occur. (14-5)

10. An aircraft ignition switch completes a circuit when it is in the OFF position, and a conventional ignition switch opens a circuit when it is in the OFF position. (14-11)

11 A regulated TEN system provides an even rate of sparking, and an unregulated TEN system fires the igniter at an uneven frequency. (15-6, 7)

12. The output voltage of the nonregulated system dynamotor is 830 volts. (15-10)
13. "Generator action" means that the generator field is energized by its own output. (15-14)
14. Capacitors C6 and C7 in the TEN ignition systems provide protection against feedback by providing a bypass to ground for radiofrequency currents. (15-11, 15)
15. The regulated TEN system incorporates a carbon-pile voltage regulator that tends to produce a constant dynamotor output voltage regardless of variations in battery voltage. (15-15)
16. The igniter plug in the TEN-1 system ceases conduction when capacitors C1 and C2 discharge. (15-25)
17. The sparking rate of the TEN-1 system is increased by moving the start switch to the AIR-START position. This lowers the time required to charge the grid capacitor and the sparking rate is increased (15-30)
18. The three systems are the cowl flap system, oil cooler system and ADI system. (16-1)
19. The cowl flap system controls the air flow through the system. (16-2)
20. The magnetic brake prevents the actuator motor from coasting. (16-3)
21. The "open" limit switch opens the circuit if the control switch is left in the OPEN position. (16-4)
22. Air flow must be reduced if engine temperature is to increase. (16-5)
23. A potentiometer allows the pilot full control of cowl flaps within their limits of travel. (16-7)
24. A change in resistance of the pot in the cockpit creates a difference of potential across the micro-positioner coil and this causes current to flow in the coil. (16-8)
25. Installing a heat sensor to work in conjunction with the potentiomemeter would provide automatic operation. (16-9)
26. Two adjustable limit switches control the linear movement. (16-11)
27. Current flow through the "brake" coil will release the brake. (16-13)
28. Two condensers provide radio noise free operation. (16-15)
29. A water-alcohol mixture is injected into the engine cylinders to prevent detonation. (16-17)
30. A centrifugal pump driven by a 28-volt dc motor. (16-18)
31. Electrical power for the ADI is supplied by 28-volt dc bus. (16-19)

Chapter 6

1. The amount of lighting required by aircraft is partially determined by the number of crewmembers and size. Since fighters are smaller and have fewer crewmembers, more lighting systems are needed on bomber and cargo aircraft. (17-1)
2. If the primary instrument lights fail, floodlights illuminate the instruments. (17-2)
3. If the secondary winding of the autotransformer shown in figure 47 were open, the integral instrument lights would not light. (17-3; Fig. 47)
4. The red lenses on the cockpit instrument floodlights help to reduce night blindness. (17-4)
5. The white floodlights are connected to the dc bus system because they are the emergency lights and they can be used when ac power fails. (17-5)
6. When the pushbutton on the utility light is pushed, the intensity control has no effect on the light, so it burns at its greatest brilliance. (17-6)

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7. Cargo aircraft have cabin and cargo compartment lights in addition to the cockpit lights found on fighter-type aircraft. (17-8)
8. The wheel well lights, besides being used for illumination of the wheel well in flight, provides light for single point refueling when the aircraft is on the ground. (17-10)
9. Landing and taxi lights are designed to provide illumination on other objects. Position and formation lights are designed to attract attention or to be seen. (18-1)
10. To prevent the nosegear landing lights from being turned on accidentally, the landing gear must be down and locked before the light will come on. (18-3)
11. In order to have an effective crosswind landing light, the front wheels must be steerable. (18-4)
12. The wing-mounted taxi lights on some tanker aircraft are used to provide light during refueling operations. (18-8)
13. If you see a flying aircraft with a green light to your right, the aircraft is going away from you. (18-9)
14. Lights are switched from a 28-volt ac bus to one of 14-volt ac when they are switched from BRIGHT to DIM. (18-10)
15. A dc motor drives a rotary cam which opens and closes the flasher contacts. (18-12)
16. The ANTICOLLISION LIGHTS are designed to flash in order to attract attention of the crew of any near-by aircraft and thereby help to prevent a collision. (18-13)
17. One of the ANTICOLLISION LIGHTS is served by a larger circuit breaker than the other because the circuit breaker also provides power for the fuselage lights. (18-14)
18. The fuselage lights discussed in this chapter are dual filament bulbs. The higher wattage filament is energized for bright lights, while, the lower wattage filament is energized for dim lights. (18-16)
19. Tanker-type aircraft produce a coded signal by controlling the color and also by controlling whether a high or low beam is shown from the rendezvous lights. (18-18)
20. When checking a circuit with an ohmmeter, incorrect readings may result if the section of the circuit being checked is not isolated. (19-6)
21. When a voltage is found on the ground side of a component, an open ground is indicated. (19-9)
22. In a window anti-ice system, the Nesa window is constructed of an inner glass pane, a layer of vinyl plastic, the Nesa compound, and the outer pane. (20-2)
23. The function of the controller amplifier in the Nesa window anti-ice circuit is to control the heat of a window by means of a bridge circuit between the sensing element and the controller amplifier. (20-6)
24. The purpose of a thermal switch in the Nesa window anti-ice circuit is to remove power from the window in approximately 10 minutes if the temperature is 70° F. (20-14)

STOP— 1. MATCH ANSWER SHEET TO THIS EXERCISE NUMBER. 2. USE NUMBER 1 PENCIL.

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VOLUME REVIEW EXERCISE

Carefully read the following:

DO'S

1. Check the "course," "volume," and "form" numbers from the answer sheet address tab against the "VRE answer sheet identification number" in the righthand column of the shipping list. If numbers do not match, take action to return the answer sheet and the shipping list to ECI immediately with a note of explanation.

2. Note that numerical sequence on answer sheet alternates across from column to column.

3. Use only medium sharp # 1 black lead pencil for marking answer sheet.

4. Circle the correct answer in this test booklet. After you are sure of your answers, transfer them to the answer sheet. If you *have* to change an answer on the answer sheet, be sure that the erasure is complete. Use a clean eraser. But try to avoid any erasure on the answer sheet if at all possible.

5. Take action to return entire answer sheet to ECI.

6. Keep Volume Review Exercise booklet for review and reference.

7. If *mandatorily* enrolled student, process questions or comments through your unit trainer or OJT supervisor.
   If *voluntarily* enrolled student, send questions or comments to ECI on ECI Form 17.

DON'T

1. Don't use answer sheets other than one furnished specifically for each review exercise.

2. Don't mark on the answer sheet except to fill in marking blocks. Double marks or excessive markings which overflow marking blocks will register as errors.

3. Don't fold, spindle, staple, tape, or mutilate the answer sheet.

4. Don't use ink or any marking other than with a # 1 black lead pencil.

Note: The 3-digit number in parenthesis immediately following each item number in this Volume Review Exercise represents a Guide Number in the Study Reference Guide which in turn indicates the area of the text where the answer to that item can be found. For proper use of these Guide Numbers in assisting you with your Volume Review Exercise, read carefully the instructions in the heading of the Study Reference Guide.

Multiple Choice

Chapter 1

1. (301) In the antiskid control system, the wheel brakes are

   a. released when the V relay is energized.
   b. released when the W relay is energized.
   c. applied when the W relay is energized.
   d. applied when the skid detector contacts are closed.

2. (301) In the antiskid control system, the skid contacts in the skid detector

   a. open the ground circuit for the W relays.
   b. complete the ground circuit for the V relays.
   c. close when the aircraft wheel speed decelerates relative to the detector flywheel speed
   d. open when the aircraft wheel speed decelerates relative to the detector flywheel speed.

3. (302) What actuates the landing gear warning horn?

   a. The throttle linkage.
   b. The landing gear handle.
   c. The uplock limit switch.
   d. The downlock limit switch.

4. (300) In the heavy aircraft landing gear system discussed in the text, the function of the landing gear lock switches is to

   a. complete the ground circuit to the position indicators only when the gear is up and locked
   b. break the ground to the position indicator unless the gear is in the up-and-locked or down-and-locked position.
   c. complete the ground circuit to the position indicators only when the gear is down and locked
   d. break the ground circuit to the warning light when any gear is in the unlocked position.

5. (302) How is the nose gear extended after pulling the emergency handle on a fighter landing gear system?

   a. Hydraulically.
   b. Electrically.
   c. Mechanically.
   d. Pneumatically.

6. (300) In the heavy aircraft landing gear system, what switch or switches must close before the spring-loaded solenoid can release the lock on the landing gear control lever?

   a. The nose centering switch.
   b. The main gear safety switches.
   c. The main gear truck leveling switches.
   d. All of the above.

7. (300) On a heavy aircraft type landing gear system, the main gear is prevented from retracting by all of the following *except* the

   a. gear safety switch.
   b. truck leveling switch.
   c. landing gear lock switches.
   d. nose gear center switch.

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Chapter 2

8 (303) During ground operation, the warning horn in the wing flap control system will operate when the

a. flap retract limit switches complete a circuit to ground.
b. flap extend limit switches complete a circuit to ground.
c. flaps are not fully extended and the number 3 and number 4 throttles are advanced above the IDLE position.
d. flaps are not fully extended and the number 4 and number 6 throttles are advanced above the IDLE position.

9. (304) In the stabilizer trim heater circuit, the overheat switch may be checked by

a. applying dry ice to the thermostat.
b. placing a jumper wire across the thermostat.
c. shorting out the heating elements.
d. closing the stabilizer trim heater circuit breaker.

10. (304) In the stabilizer trim control circuit, the direction of rotation of the

a. actuator motor is reversed by reversing the phase sequence of the applied voltage.
b. actuator motor is the same, regardless of which relay is energized.
c. actuator motor depends upon which clutch in the clutch pack is energized.
d. followup screw is always the same, regardless of which relay is energized.

11. (303) The limit switches in the leading-edge flap H-BOX energize the

a. TAKEOFF CONTROL RELAY.
b. FLAP LOCK MOTOR.
c. DOWN LIMIT SWITCH.
d. MAGNETIC BRAKE.

12. (304) The aileron trim control system discussed in the text is powered

a. electrically only.
b. pneumatically only.
c. electrically and hydraulically.
d. electrically and pneumatically.

13. (304) In the aileron trim control circuit, trim power cannot be applied to both fields of the trim actuator motor at the same time because of the

a. MAGNETIC BRAKE.
b. MOTOR LIMIT SWITCH
c. TRIM SELECTOR SWITCH.
d. TAKEOFF TRIM RECTIFIERS.

Chapter 3

14 (306) In a fire warning circuit containing thermocouple fire detectors, the fire warning light flashes on when

a. there is a rapid rise in temperature.
b. the reference junction temperature rises.
c the temperature reaches a predetermined value.
d the thermal switch completes a circuit to ground.

15. (308) In the bailout warning system, the crewmembers are alerted when the indicator light is on

a. steady red.
b. flashing red.
c. steady amber.
d. flashing amber.

16. (305) A thermal switch will close when exposed to a certain temperature because the

a two different metals when heated produce electricity.
b. outer shell has a high coefficient of expansion.
c. internal elements have high coefficients of expansion.
d. switch blade that holds the pair of contacts will expand.

17. (306) One factor that determines the number of thermocouples that should be used in an individual detector circuit is the

a. total detector circuit resistance.
b. number of slave relays being used.
c. size of the thermocouple relay box.
d. expected thermal test unit temperature.

18. (308) The warning lights in most door warning circuits are activated by

a. opening a switch.
b. depressing a switch.
c. grounding a circuit.
d. applying a voltage.

19. (306) The amplifier in a photoelectric fire warning system is sensitive to signals

a. of infrared rays.
b. of all frequencies.
c. from solar radiation.
d. in a certain frequency range.

20. (308) The master warning and caution system lamp assemblies' voltage on aircraft is

a. 28 volts dc.
b. 28 volts ac.
c. 28 millivolts dc.
d. 28 microvolts ac.

21. (307) In the continuous cable fire warning circuit in a four-engine aircraft, the sensing element loop consists of two

a. dissimilar wires which produce a voltage when heated.
b. wires inside a metal tube capacitor coupled to a fire warning amplifier.
c. wires that expand when heated and cause the electrical contacts to close.
d. wires separated by an insulating material having a negative coefficient of resistance.

22. (308) In the master warning and caution system discussed in the text, with the autorest switches closed,

a. the dimming switch is used to energize the light test relay.
b. both dimming relays will energize when the dimming switch is held in the BRIGHT position.
c. dimming relay A forms the holding circuit for dimming relay B.
d. dimming relay B forms the holding circuit for dimming relay A.

23. (308) The operation of the smoke detector warning circuit in the cargo compartment of an aircraft depends upon the

a. radiation of the photocell.
b. temperature around the photocell.
c. light being reflected to the photocell.
d. frequency of light that activates the photocell.

24. (306) In a thermocouple fire warning circuit, the

a. total current should not exceed 0.004 milliampere.
b. total circuit resistance should not exceed 5 ohms.
c. contacts are mounted on nickel-iron struts having a low expansion coefficient.
d. resistor across the therminals of the sensing relay prevents arcing at the slave relay terminals.

25. (308) The purpose of the ground protection relay in the master warning and caution system is to

a. allow operation of the lamp assemblies when the aircraft is connected to an external power source.
b. prevent testing of the lamp assemblies except when the aircraft is furnishing its own electrical power.
c. complete the ground circuit for the lamp assemblies when the aircraft is furnishing its own electrical power.
d. break the ground circuit for the lamp assemblies when the warning and caution override switch is moved out of the NORM position.

26. (306) During a polarity check of a thermocouple fire warning circuit, the polarity of the thermocouples is correct if the

    a. thermocouple resistance is minimum.
    b. meter deflects in a counterclockwise direction.
    c. thermocouple leads are connected positive to positive and negative to negative.
    d. meter deflects in a clockwise direction.

27. (306) In the photoelectric fire warning system, fluctuating resistance in the photoconductive cell serves to

    a. radiate current flow.
    b. generate a low frequency.
    c. produce the fire signal.
    d. vary inductance in the circuit.

28. (307) In the continuous cable fire warning assembly, the cable is tested with the test relay that

    a. places a ground on the cable.
    b. applies 28 vdc to the cable.
    c. completes the loop to the cable.
    d. connects the thermal circuit to the cable.

Chapter 4

29. (310) In multiengine aircraft, most all fuel system fire shutoff valves are of the

    a. float control type.
    b. solenoid closing type.
    c. motor-driven plug type.
    d. motor-driven sliding gate type.

30. (310) The fuel system main tank boost pump switch is set to close the circuit to the green pressure check-out indicator light at approximately

    a. 4 psi.
    b. 6 psi.
    c. 8 psi.
    d. 10 psi.

31. (312) What unit *directly* controls the fuel scavenge pump?

    a. The toggle switch.
    b. The float switch.
    c. The solenoid-operated, gate-type valve.
    d. The solenoid-operated, shuttle-type valve.

32. (312) Which one of the following events will *not* cause the DISCONNECT light in an air refueling system to illuminate?

    a. The main fuel tanks reach full by weight.
    b. A disconnect signal is sent from the tanker.
    c. Excessive fuel pressure is in the refuel cabin manifold.
    d. A break in contact between the boom nozzle and the receptacle.

33. (312) The purpose of the amber light in the fuel scavenge system is to indicate that the

    a. manifold does not contain fuel.
    b. scavenge pump is not working.
    c. manifold contains fuel.
    d. scavenge pump is working.

34. (310) The pump discharge pressure of individual fuel boost pumps is checked by

    a. routing fuel to the crossfeed manifold.
    b. filling the main fuel tanks to capacity.
    c. observing the amber fuel flow indicator lights.
    d. taking pressure gage readings at the control valves.

35. (313) When the load on a dc series starter motor is increased, the field flux is

a. increased and the motor speed is increased.
b. increased and the motor speed is decreased.
c. decreased and the motor speed is increased.
d. decreased and the motor speed is decreased.

36. (314) In the pneumatic starter system employed on some aircraft, the device that prevents overpressurization of the starter is the

a. safety disc.
b. pilot valve.
c. overrunning clutch.
d. pressure-relief squib.

37. (317) Under normal conditions, what switch turns the ignition off to the fuel-air starter?

a. Starter switch.
b. Burner switch.
c. Centrifugal switch.
d. Time-delay switch.

38. (317) To fire the igniter plugs on jet engines using the TEN-1 type ignition system, the high-voltage power is supplied by

a. a battery.
b. an exciter.
c. a dynamotor.
d. high-tension transformers.

39. (319) On reciprocating engine aircraft, which power plant system controls the flow of air past the cylinders?

a. Cowl flap system.
b. Carburetor air door.
c. Oil cooler flap system.
d. Centrifugal pump system.

40. (316) When the ignition is in the OFF position on a reciprocating engine of an aircraft, the

a. secondary circuit is opened.
b. primary coil is grounded out.
c. meshing switch is deenergized.
d. ignition switch circuit is opened.

41. (319) What electrical component provides the pilot with full control of the cowl flap system?

a. Limit switches.
b. Micropositioner.
c. Cockpit potentiometer.
d. Followup potentiometer.

42. (317) The test switch on the nonregulated jet engine ignition system is used to check the

a. sparking rate control circuit.
b. air-start and ground-start systems.
c. functioning of each igniter plug.
d. time delay of the air-start circuit.

43. (314) During normal operations, the ignition to the fuel-air starter is terminated by operation of the

a. burner switch.
b. starter switch.
c. time-delay switch.
d. centrifugal switch.

44. (316) In a single-engine ignition system, if a ground exists in the P-lead between the right magneto and the ignition switch, the

a. right magneto will operate, regardless of the position of the ignition switch.
b. left magneto will *not* operate when the ignition switch is in the BOTH position.
c. left magneto will operate when the ignition switch is in the R position.
d. left magneto will operate when the ignition switch is in the L position.

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45. (319) The purpose of the oil cooler flap is to control the

a. oil flow through the cooler.
b. air flow through the cooler.
c. air pressure in the cooler.
d. oil pressure in the cooler.

46. (318) Where, in the TEN-1 ignition system, is the energy that is required to fire the igniter plug stored?

a. Capacitors.
b. Choke coils.
c. Transformers.
d. Induction coils.

47. (319) What component acts as a noise filter in the oil cooler flap circuit?

a. Condenser.
b. Actuator coils.
c. Magnetic brake.
d. Limit switches.

48. (314) The pressure-relief squib in the cartridge pneumatic starter provides protection

a. against excessive turbine speeds.
b. against excessive breech pressure.
c. preventing rupture of the pressure-relief valve.
d. preventing cartridge gas from venting to the exhaust of the starter.

49. (319) Which of the following systems is intended to prevent detonation in a reciprocating engine?

a. Cowl flap system.
b. Oil cooler system.
c. Water injection system.
d. Carburetor air temperature system.

50. (314) If the control relay on a fuel-air starter fails to energize, the most probable cause of trouble is

a. a shorted turbine centrifugal switch.
b. an open gearbox centrifugal switch.
c. an open low-pressure burner switch.
d. a shorted high-pressure burner switch.

51. (315) When using the Prony brake to test a starter, the

a. starter jaw must be fully retracted before the starter is operated.
b. high reading torquemeters are used to check actuator rotation.
c. starter jaw must be fully extended before the starter is engaged.
d. maximum input voltage to the component is used when checking no-load operations.

52. (317) The dynamotor used in the nonregulated TEN-1 ignition system consists of

a. an ac shunt-wound motor and dc generator.
b. an ac shunt-wound motor and ac generator.
c. a dc shunt-wound motor and dc generator.
d. a dc shunt-wound motor and ac generator.

53. (314) In using cartridge pneumatic starters, the pressure-relief squib should always be handled with extreme care because of its sensitivity to

a. pressure.
b. electricity.
c. magnetism.
d. temperature.

54. (319) The ADI system on a reciprocating engine aircraft is used

a. on all power settings.
b. during cruise power settings.
c. only during low power settings.
d. only during high power settings.

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55. (321) Certain exterior aircraft lights are designed to flash on and off in order to

a. attract attention.
b. prevent night blindness.
c. conserve electrical power.
d. indicate a distress condition.

56. (321) When the crosswind landing light is used, it is pointed in the same direction as the

a. aircraft.
b. steerable wheels.
c. steering wheel.
d. crosswind source.

57. (322) What is the function of the autotransformer in the NESA window circuit?

a. Step-down transformer.
b. Step-up transformer.
c. A branch of the bridge control circuit.
d. A power supply for the sensing circuit.

58. (321) By routing the control circuit through the left main landing gear down limit switch, the landing light is prevented from coming on until the

a. landing gear is locked down.
b. landing gear is up and locked.
c. aircraft is on the ground.
d. aircraft is on final approach.

59. (321) Circuit analysis is best performed by using

a. test voltmeters.
b. a block diagram.
c. the actual circuit.
d. a schematic of the circuit.

60. (321) Which of the other lighting systems does the circuitry for the taxi light parallel throughout?

a. The headlight circuit.
b. The landing light circuit.
c. The formation light circuit.
d. The rendezvous light circuit.

61. (321) You can tell (from the ground) whether a night-flying aircraft is going away from you or approaching you by observing the

a. taxi lights.
b. rendezvous lights.
c. fuselage lights.
d. navigation lights.

62. (321) Which type of aircraft is equipped with a rendezvous lighting system?

a. Tanker.
b. Bomber.
c. Cargo.
d. Fighter.